National Center for Intermodal Transportation for Economic Competitiveness

Final Report 524

Development of a Highway Safety Fundamental Course

by

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University of Louisiana at Lafayette

NCITEC
National Center for Intermodal Transportation for Economic Competitiveness

Supported by:

MISSISSIPPI STATE UNIVERSITY

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/LA.14/524		

4. Title and Subtitle	5. Report Date
Development of a Highway Safety Fundamental Course	May 2015
	6. Performing Organization Code LTRC Project Number: 13-2SA State Project Number: 30000761
7. Author(s) Xiaoduan Sun, Ph.D., P.E.	8. Performing Organization Report No.
9. Performing Organization Name and Address Civil Engineering Department University of Louisiana at Lafayette Lafayette, LA 70504	10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Center for Intermodal Transportation for Economic Competitiveness (NCITEC) Mississippi State University 260 McCain Miss. State, MS 39762 Louisiana Department of Transportation and Development P.O. Box 94245 Baton Rouge, LA 70804-9245	13. Type of Report and Period Covered **Final Report** **July 1, 2012 to December 31, 2013** 14. Sponsoring Agency Code

15. Supplementary Notes

Conducted in Cooperation with the U.S. Department of Transportation, Research and Innovative Technology Administration (RITA), Federal Highway Administration

16. Abstract

Although the need for road safety education was first recognized in the 1960s, it has become an increasingly urgent issue in recent years. To fulfill the hefty goal set up by the AASHTO Highway Safety Strategy and by state DOTS, it is critical to have a workforce that fully understands the fundamentals of highway safety. One way to ensure such an adequate workforce is to develop a college level course to educate students. Although the NCHRP Project 17-40, "Model Curriculum for Highway Safety Core Competencies," has produced training materials on highway safety, it targets a broad audience "that consists of road safety professionals at all levels of government, as well as representatives of the private sector and non-profits, from the fields of: traffic engineering, highway safety, public health, psychology, statistics, law enforcement, economics, planning, public policy, and education." The course title "Road Safety 101" clearly shows that it is not intended for a systematic safety education in the field of engineering.

This project developed a teaching package for safety fundamentals for undergraduate students and graduate students in civil engineering. The course covers seven topics: introduction to highway safety, basic safety concepts, safety related data, fundamental statistics, development of safety models, safety predictive models in HSM, and safety evaluation. Accordingly, seven lecture notes were developed along with homework assignments, quizzes, and exams.

The developed course materials can also be used in the engineering continuing education on the topic of roadway safety and in roadway safety training workshops for a broad audience who are involved in highway safety from not just engineering, but also education and enforcement.

17. Key Words	18. Distribution Statement
	Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price

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ABSTRACT

Although the need for road safety education was first recognized in the 1960s, it has become an increasingly urgent issue in recent years. To fulfill the hefty goal set up by the AASHTO Highway Safety Strategy and by state DOTS, it is critical to have a workforce that fully understands the fundamentals of highway safety. One way to ensure such an adequate workforce is to develop a college level course to educate students. Although the NCHRP Project 17-40, “Model Curriculum for Highway Safety Core Competencies,” has produced training materials on highway safety, it targets a broad audience “that consists of road safety professionals at all levels of government, as well as representatives of the private sector and non-profits, from the fields of: traffic engineering, highway safety, public health, psychology, statistics, law enforcement, economics, planning, public policy, and education.” The course title “Road Safety 101” clearly shows that it is not intended for a systematic safety education in the field of engineering.

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ACKNOWLEDGMENTS

The help and guidance from the project review committee is appreciated. Special appreciation goes to the project manager, Kirk M. Zeringue, for his diligent work to ensure the project executed successfully with intended results.

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INTRODUCTION

Although the need for road safety education was first recognized in the 1960s, it has become an increasingly urgent issue in recent years. To fulfill the hefty goal set up by the AASHTO Strategic Highway Safety Plan (cutting traffic fatalities in half by 2020) and by the state (Destination Zero Death by Louisiana Strategy Highway Safety Plan), it is critical to have a workforce that fully understands the fundamentals of highway safety. The fundamental knowledge of roadway safety has evolved during the two decades. The first edition of Highway Safety Manual (HSM) documented the latest fundamental knowledge on highway safety. Ensuring that newly-entering engineering students are equipped with a sufficient background in highway safety is critical to sustaining the progress of reducing the number of crashes in recent years. Therefore, one way to ensure such an adequate workforce is to develop a college level course to educate students, which has not been done in the past.

Although the NCHRP Project 17-40, "Model Curriculum for Highway Safety Core Competencies," has produced training materials on highway safety, it targets a broad audience "that consists of road safety professionals at all levels of government, as well as representatives of the private sector and non-profits, from the fields of: traffic engineering, highway safety, public health, psychology, statistics, law enforcement, economics, planning, public policy, and education". The course title "Road Safety 101" clearly shows that it is not intended for a systematic safety education in the field of engineering *[1]*.

Preparing engineering students for future work in highway safety is particularly important in this region because of a poor performance in highway safety. As shown in Figure 1, the traffic fatality rate (fatalities per 100 million Vehicle-Miles-Traveled) in Louisiana and Mississippi has been persistently higher than the national average, although the fatality rate has been reduced over the last several years *[2]*. Traffic crashes bring a hugely negative impact not only on public health but also on sustainable economic development due to lost productivities, lost wages and salaries, medical and long-term care cost, property damage, and travel delay. The need to improve highway safety is significant in this region.

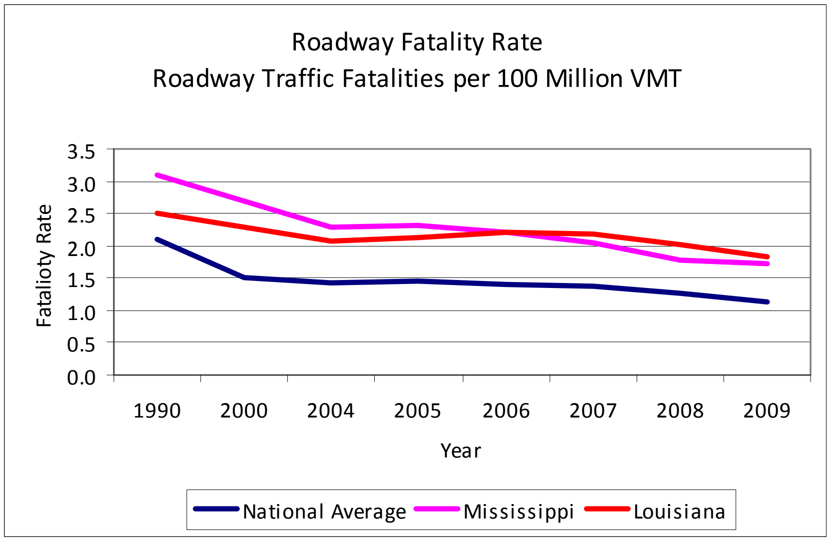

Figure 1
Traffic fatality rate by year

Increasing the workforce short-and long-term competitiveness in highway safety in this region will help the sustainable economic development.

OBJECTIVE

The goal of this project was to develop much needed roadway safety fundamentals for undergraduate and graduate students for the NCITEC consortium universities. The developed course materials can be used for college education in a classroom setting or for workforce training in a workshop setting.

SCOPE

The scope of this project includes a teaching package for highway safety fundamentals, which can be used in a university setting or for an on-site job training program for engineers. The final product of the project will consist of the lecture notes and student assignments.

METHODOLOGY

Due to the nature of this project, three sections are included in this section of the report.

Review

Highway safety education and training have been recognized as an important step in reducing the number of crashes and crash severities. Currently, there are many professional training programs available in the United States. As part of NCHRP 20-70 project, Geni B. Bahar has identified a total of 184 training courses by various organizations *[3]*. The focus of these training programs varies by the targeted audience in the 4E areas.

F. Gross and P. Jovanis, working with the TRB Joint Subcommittee for Highway Safety Workforce Development, published a set of safety core competencies and learning objectives that outline the "fundamental knowledge and skills that should be possessed by all transportation safety professionals"*[4]*. The core competencies are as follows:

1. Understand the management of highway safety as a complex, multidisciplinary system;
2. Understand and be able to explain the history of highway and institutional settings in which safety management decisions are made;
3. Understand the origins and characteristics of traffic safety data and information systems to support decisions using a data-driven approach in managing highway safety;
4. Demonstrate the knowledge and skills to assess factors contributing to highway crashes, injuries, and fatalities, identify potential countermeasures linked to the contributing factors, apply countermeasures to user groups or sites with the promise of crash and injury reduction, and implement and evaluate the effectiveness of the countermeasures; and
5. Be able to develop, implement, and manage a highway safety management program.

The TRB Special Report 289 "Building the Road Safety Profession in the Public Sector" stated that *[5]:*

- Road safety is a major responsibility of governments at all levels;
- Road safety management must be guided by science and safety system perspective;
- Road safety management requires a talented and diverse workforce;
- Road safety professionals must possess a common body of knowledge and skills;

- Education and training for road safety are scarce;
- Career advancement in the road safety profession is limited;
- The need for road safety professionals is growing;
- More attention must be given to building the supply of safety professionals

Road Safety 101 was developed as a result of NCHRP 17-40 Project "Model Curriculum for Highway Safety Core Competencies." It is currently an online or on-site certificate training program aiming to teach the basics of road safety offered by the institutes affiliated with FHWA. This course enables users to understand the elements of successful road safety programs, identify contributing crash factors and how they interact as well as gain a better understanding of road safety data collection and systems *[2]*.

After the publication of the first edition of the HSM, many professional training courses or programs quickly incorporated HSM content into training materials. Additionally, the HSM Online Overview became available free of charge through the National Highway Institute (NHI) website *[6]*. This course consisted of 13 self-paced informational modules that can be taken in any order, depending on the user's prior knowledge and experience, interest, and time available. The course includes an introduction of HSM terminology, examples of the Roadway Safety Management Process (HSM Part B) and Predictive Methods (HSM Part C), explains the relationship of crash modification factors (CMFs) to decision making and quantitative safety analysis, and human factors *[7]*.

In addition to teaching roadway safety as part of a transportation engineering course, quite a few universities currently offer a full highway safety course in civil engineering with a focus on roadway engineering. The University of Louisiana at Lafayette started the course in 2009 as an elective course for undergraduate and graduate students. The comprehensive syllabus covered in the traditional highway safety course is described in the next section. Pennsylvania State University offers a highway safety course on human factors to expose the students to the breadth of issues related to safety and human factors in the highway transportation field. The course allows the students to gain experience in the recognition of problems, formulation of methodologies, analysis of data, and development of solutions.

Teaching Package Development

A detailed teaching package on the safety fundamentals was developed, which includes:

1. Lecture notes in PowerPoint presentation format
2. Homework assignment
3. Project assignment
4. Quizzes and exams

The content of the package covers the fundamental highway safety in the following topics:

1. Introduction to Highway Safety
2. Basic Safety Concepts
3. Safety Data
4. Fundamental Statistics
5. Development of Safety Models
6. Safety Predictive Models from Highway Safety Manual (HSM)
7. Safety Evaluation

The objectives and details for each topic are summarized in the following seven tables.

Table 1
Introduction to roadway safety

Subtopic	Objectives	Content
Traffic Crash—a global underemphasized problem	Be familiar with the gravity of the problem	1. Crash statistics (global, U.S. and the state) 2. Comparing traffic crashes with other types of fatalities
Impact of crashes on a society	Recognize the multidimensional aspects of safety	1. Public health problem 2. Economic problem 3. Liability problem 4. Social problem
Dissecting a crash	Identify influential and contributing factors to a crash and its severity	1. Basic crash mechanism 2. Haddon matrix 3. How roadway, vehicle, and environmental conditions contribute to a crash occurrence and its severity

Introduction to the 4E approach	Understand the significance of the 4E approach	1. Roadway users characteristics 2. Vehicles characteristics 3. Roadways characteristics 4. Environment 5. Emergency service

Table 2

Basic safety concept

Subtopic	Objectives	Content
Defining Safety	Understand the scientific definition of safety	1. How do customers define safety 2. Objective safety and subjective safety 3. Safety definition

Table 3

Safety data

Subtopic	Objectives	Content
Safety Related Data	Understand how the crash data can be used to measure safety and the issues related to crash counts	1. Regression to the mean 2. Issues with the data quality 3. Direct measurement 4. Surrogate measurement

Table 4

Fundamental statistics

Subtopic	Objectives	Content
Fundamental Statistics	Refresh fundamental statistics related to safety analysis	1. Mean and variance estimation 2. Accuracy and standard error 3. Related probability distribution faction 4. Introduction to Empirical Bayes method

Table 5

Development of safety models

Subtopic	Objectives	Content
Introduction	Understand the purpose, development history and issues in safety models	1. The need for safety predictive models in project decision making process 2. Introduction to parametric and non-parametric modeling techniques 3. Conceptual safety predictive model
Development of Safety Models	Understand the basic steps in safety modeling process and be able to develop models with local crash data	1. Data cleaning process 2. Exploratory data analysis 3. Formulating model structure 4. Parameter estimation 5. Model fitness evaluation

Table 6

Safety predictive models from HSM

Subtopic	Objectives	Content
Safety Predictive Models from HSM	Be familiar with the safety models for three types of highways for potential safety management applications.	1. Introduction to HSM models 2. Rural 2-lane models 3. Rural Multilane models 4. Urban and suburban arterials models

Table 7
Safety evaluations

Subtopic	Objectives	Content
Introduction to safety evaluation	Understand the purpose and requirements for safety evaluation	Safety evaluation objectives and definitions
Methodology	Understand the correct way to do safety evaluation and apply the fundamental concept in roadway safety to estimate safety of a project or crash countermeasure	1. The logical basis for safety evaluation 2. General evaluation types 3. Observational nature of roadway safety evaluation 4. Before-and-after study 5. Cross-sectional study
Case studies	Be able to perform safety evaluation analysis	1. Atchafalaya I-10 Speed study 2. Lane conversion (4U to 5T) study

All seven lecture notes are listed in Appendix A. All homework, quizzes, and exams are listed in Appendix B.

Comprehensive Safety Course Syllabus

Additionally, a comprehensive safety course syllabus was developed by this project. The course is a college level class on roadway safety from mainly a roadway engineering perspective. The targeted audiences for this course are undergraduate and graduate students majoring in engineering, specifically civil engineering. The course is designed to provide basic elements of roadway safety, emphasizing the roadway engineering side of the comprehensive 4E approach. The course materials can also be used for engineering continuing education on the topic of roadway safety and in roadway safety training workshops for a broad audience who are involved in highway safety from not just engineering, but also education and enforcement.

The main goal of this course is to provide a fundamental understanding of roadway safety. Specifically, the course is designed to give students:

- Deeper understandings of interactions between driver, vehicle, and roadway
- Full awareness of safety implementations associated with roadway design, traffic control and policy decisions.
- Analyzing skills of crash statistics

The syllabus is listed in Appendix C.

DISCUSSION OF RESULTS

The results of this project are a complete teaching package for highway safety fundamentals. This teaching package consists of seven lecture notes and course evaluation materials (homework and exams). This teaching package can be utilized in whole or in part by transportation engineering courses in a university setting or professional training workshops. The PI will be available to provide a training course, if needed.

CONCLUSIONS

It is critical to teach fundamental highway safety in college to undergraduate and graduate students in order to sustain the safety improvement of the last few years.

RECOMMENDATIONS

It is recommended a training-the-trainers'effort be initiated as a follow up of this project.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
FHWA	Federal Highway Administration
HSM	Highway Safety Manual

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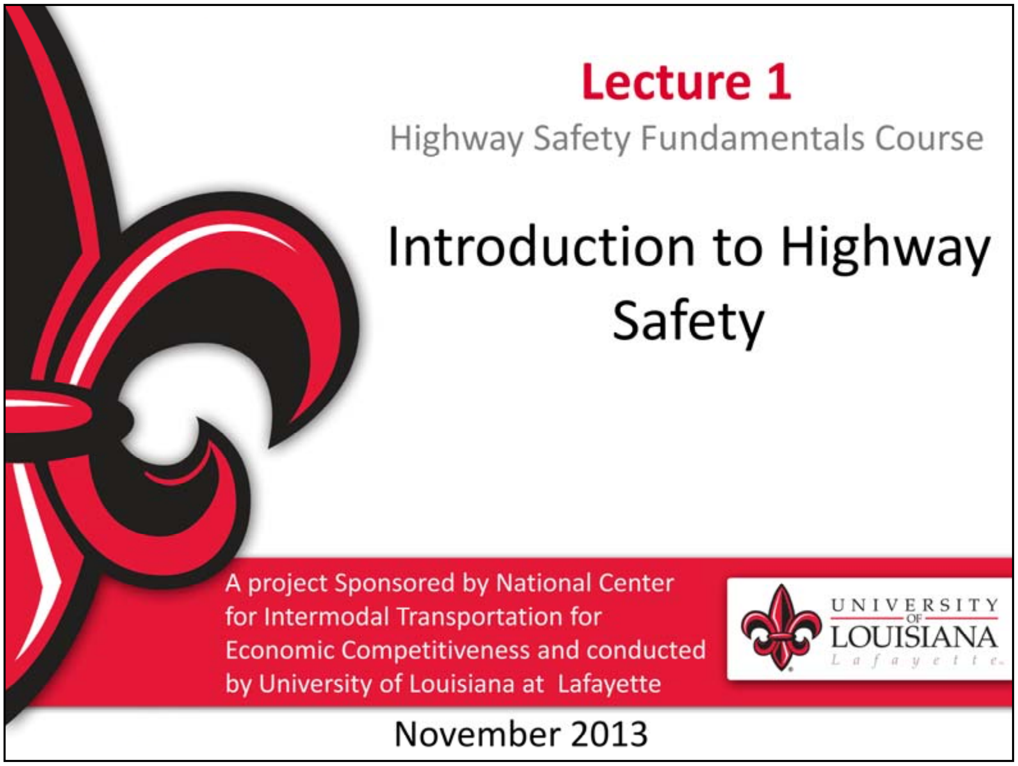
APPENDIX A: TEACHING PACKAGE

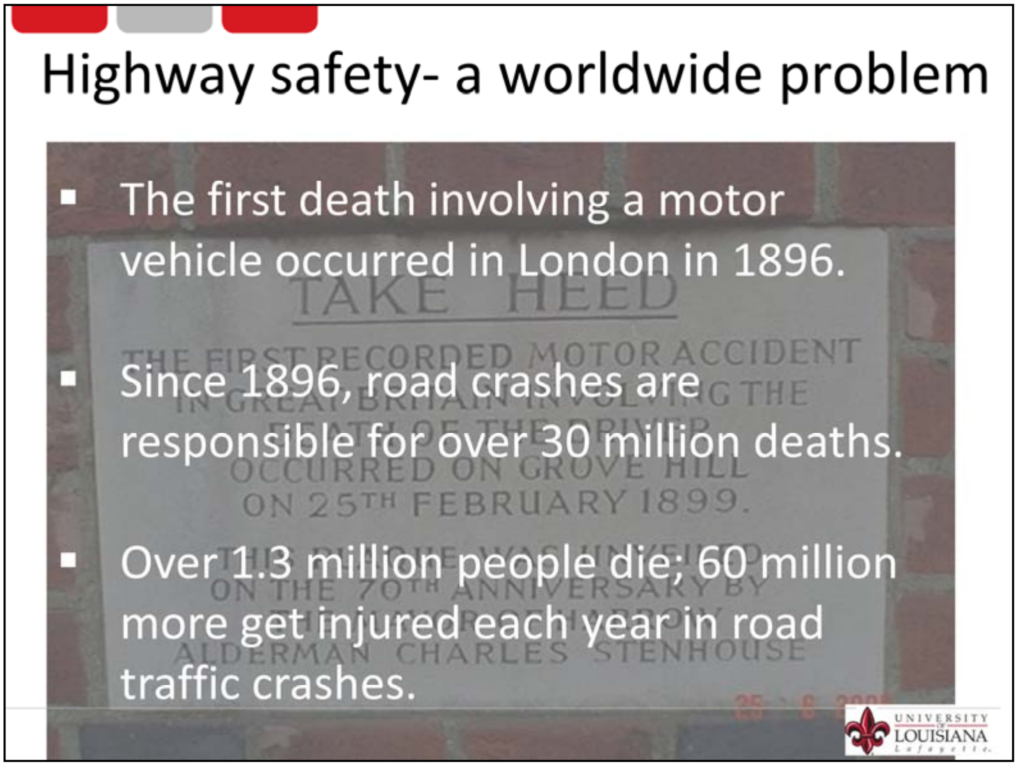


This introduction lecture aims to let students:

1. Be familiar with the gravity of the problem
2. Recognize the multidimensional aspects of safety
3. Identify influential and contributing factors to a crash and its severity

Outline

- Highway Crashes- an Underemphasized Problem
- Highway safety – a Complex field



Travel by highway is one of the most hazardous activities that people undertake particularly in developing countries.

Ref 1: http://www.trauma.org/archive/history/epidemiology.html

Ref 2: http://www.firstaidinaction.net/content/download/2633/24897/version/1/file

Ref 3: http://www.who.int/mediacentre/factsheets/fs358/en/

- About 25,850,000 people lost their lives in traffic crashes during the last century, more than the number of people who died during WWI
- About 2,235,000,000 vehicles were sold last century, 1.2 traffic fatalities per 100 vehicles manufactured

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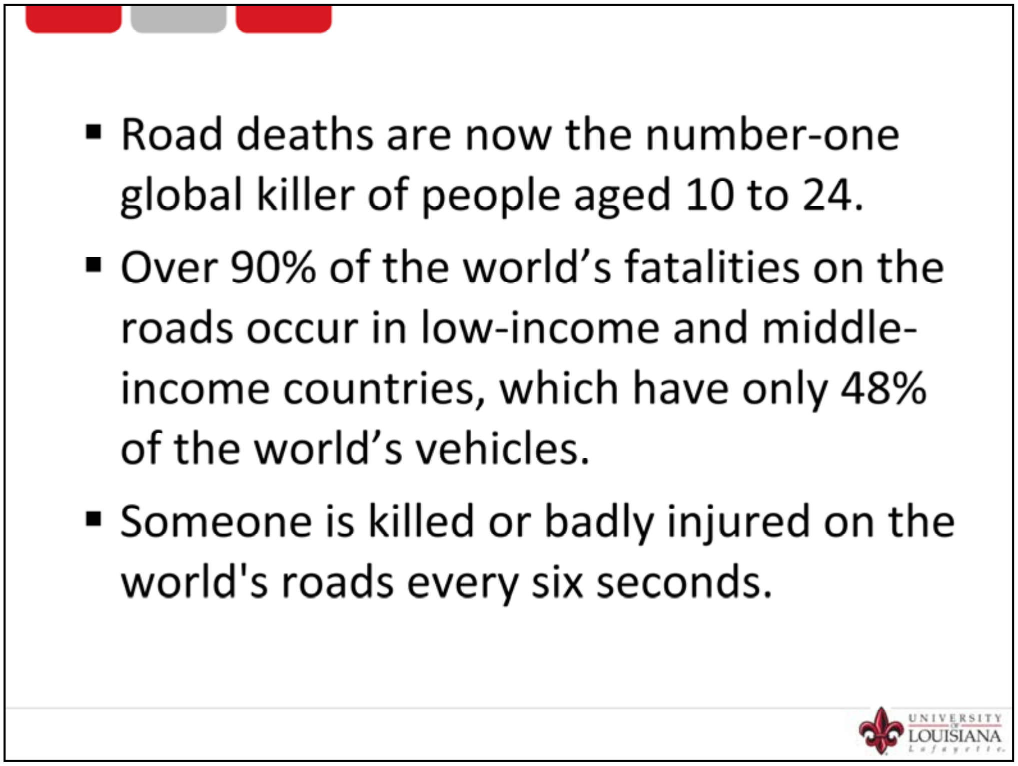
Emphasizing the side-effect of motorization in last century.



Crash problems in developing countries and in the whole world.

For example, the rate of child deaths due to road crashes in South Africa is 26 per 100,000 population, compared with 1.7 per 100,000 in Europe.

Ref 1: http://www.who.int/features/factfiles/youth_roadsafety/en/

Ref 2: http://www.who.int/violence_injury_prevention/road_safety_status/report/state_of_road_safety_en.pdf

Ref 3: http://www.roadsafetyfund.org/Pages/default.aspx

More than 3400 people die daily on the world's roads and tens of thousands are disabled for life.

Put it in perspective

Ref 1: http://www.medicalteams.org/Stories/worldwide-events

A grim problem in the U.S.

	1999	2009
Fatal Crashes	**37,140**	**30,797**
Fatalities per 10 million VMT	**1.55**	**1.09**
Population	272,690,813	307,007,000
Register Vehicles	212,685,000	257,794,000

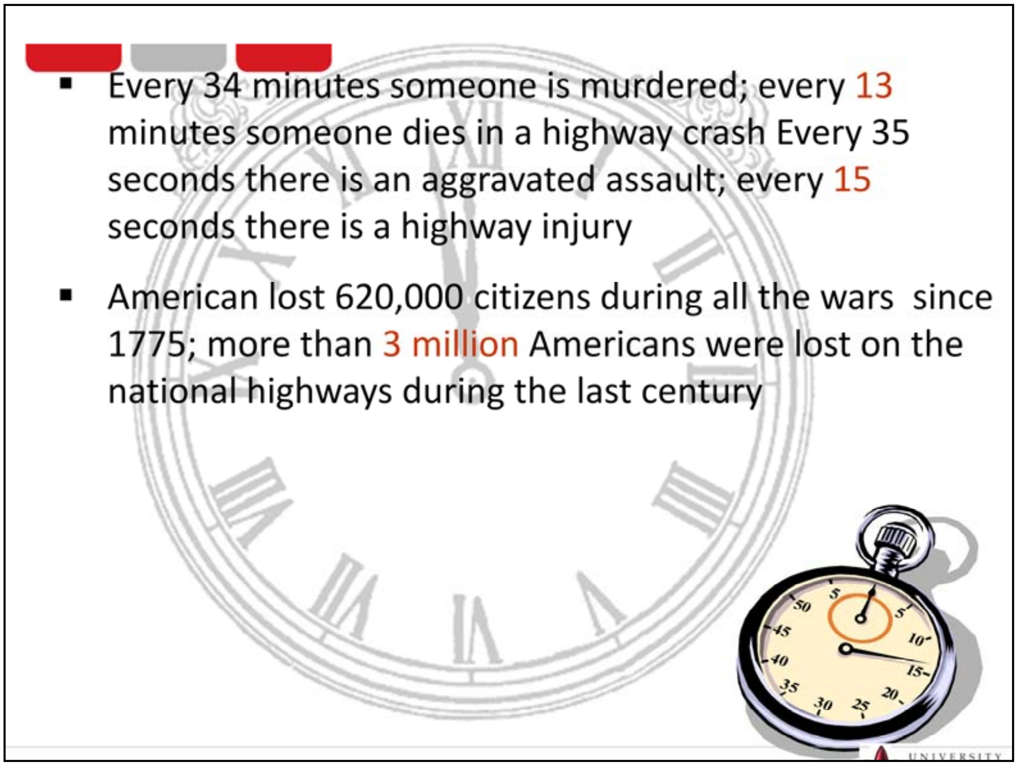
Let’s look at the U.S. statistics.

Ref 1: http://www.nhtsa.gov/FARS

Traffic Deaths at Lowest in 60 years!

Yes, improvements have been made, evidenced by the numbers; however, 2012 experienced an increase but not reaching the previous level. Why?

Ref 1: http://www.nytimes.com/2011/04/01/us/01driving.html?_r=0



People sometimes have a hard time perceiving a situation by numbers, let's compare the statistics.

Lots of effort has been made in curbing criminal activities in the U.S. in the last three decades.

Ask question: "How many people will die in crashes during this 150 minute session?"

Ref 1: self calculated

Ref 2: http://www.nap.edu/openbook.php?record_id=10223&page=72

Ref 3: http://ethanfoundation.org/home.html

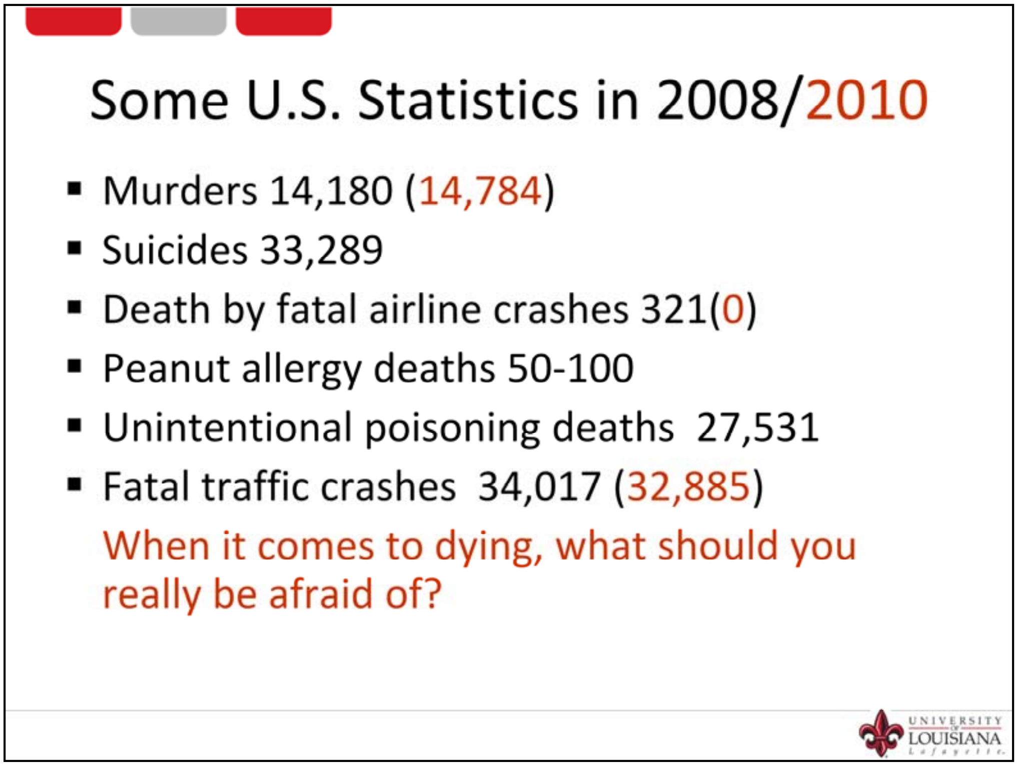
- Highway fatality accounts for 95% of transportation related deaths
- Annual death toll is equivalent to a jetliner crashing and killing every one on board each day of the year

Again, put it in perspective.

Highway safety does not receive the attention it deserves because fatality happens individually, unlike airline crashes.

Ref 1: http://www.saferoads.org/press/press2003/pr_JackeStatement5-21-03.htm

Ref 2: http://www.nap.edu/openbook.php?record_id=10223&page=71



This slide, based on a chart in Newsweek magazine, notes things that are, in Newsweek's words, "unsettling threats" and their far "riskier counterparts". Note that fatal airline crashes are an "unsettling threat" but not likely, while fatal car crashes is the "riskier counterpart" to airline crashes. The same thing is true of murders versus the far riskier threat of suicide. And the enormous difference between the threat of peanut allergy death versus the far more likely chance of dying of unintentional poisoning.

Comparison

- Car
  - In control
  - Most crashes are PDO
  - "routine" event
- Airplane
  - Beyond control
  - All die
  - Headline event

While 817 people lost their lives in passenger airplane crashes in 2010, more than 3,000 people die on roadways every day in the world.

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A crash fatality does not equal to airline fatality.

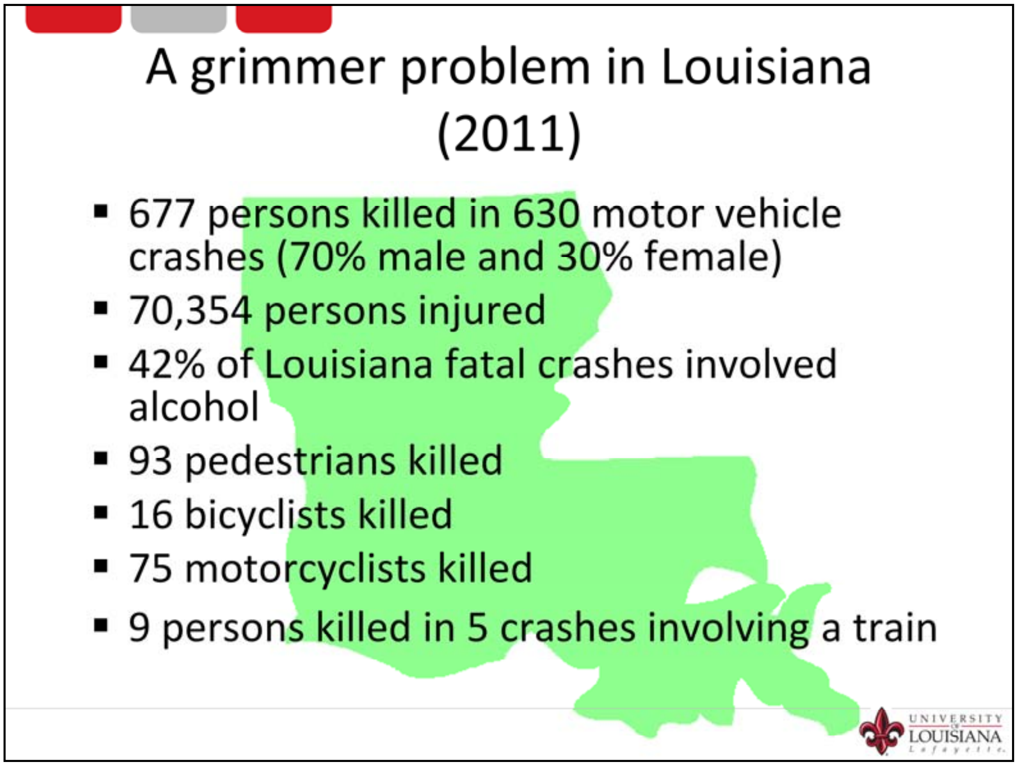
Ref 1: http://www.dailymail.co.uk/news/article-1346042/Number-passengers-killed-airline-crashes-soars-2010--safer-travelling-roads.html

Annual Worldwide Airplane Fatalities close to Annual Louisiana Traffic Fatalities

WORLD AIRLINE DEATH TOLLS	
YEAR	**DEATHS**
2001	778
2002	1,022
2003	702
2004	466
2005	1,050
2006	863
2007	744
2008	583
2009	749
2010	817

Ref 1: http://en.wikipedia.org/wiki/Aviation_crashs_and_incidents

Airline crashes are so dramatized- but look at these numbers!



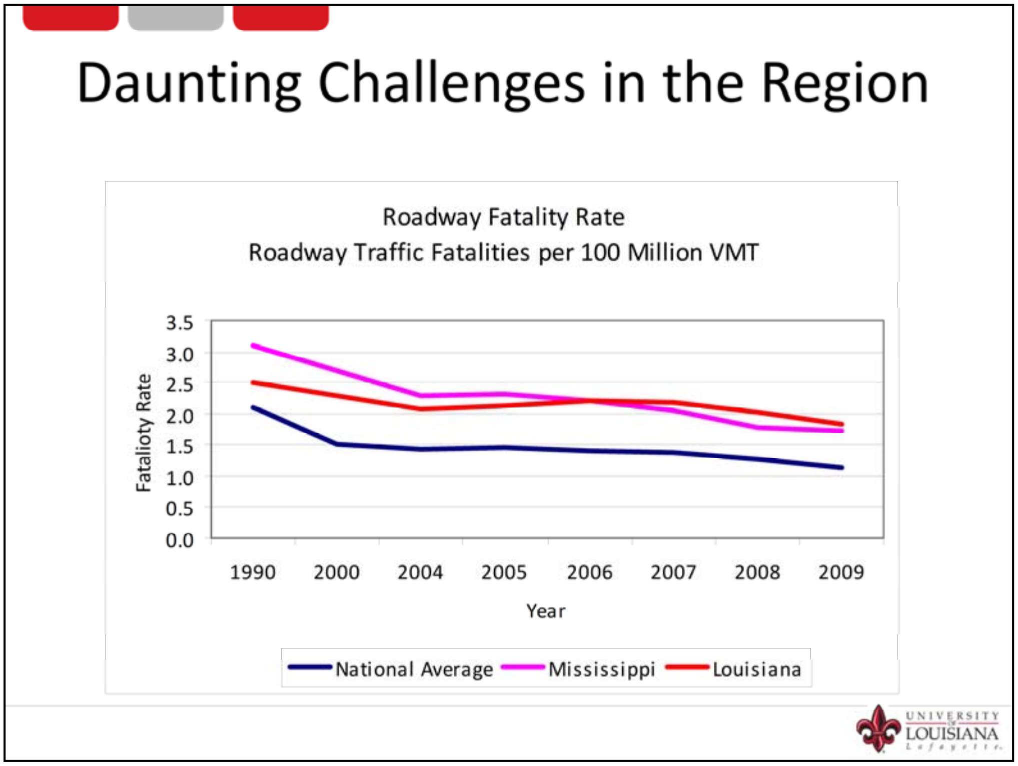
What happened each year in your state?

Here are some crash statistics of Louisiana:

- 3% (80/110) of pedestrians killed were male
- 110 pedestrians killed (8 were children aged 14 or under)

Ref : http://datareports.lsu.edu/CrashReportIndex.aspx

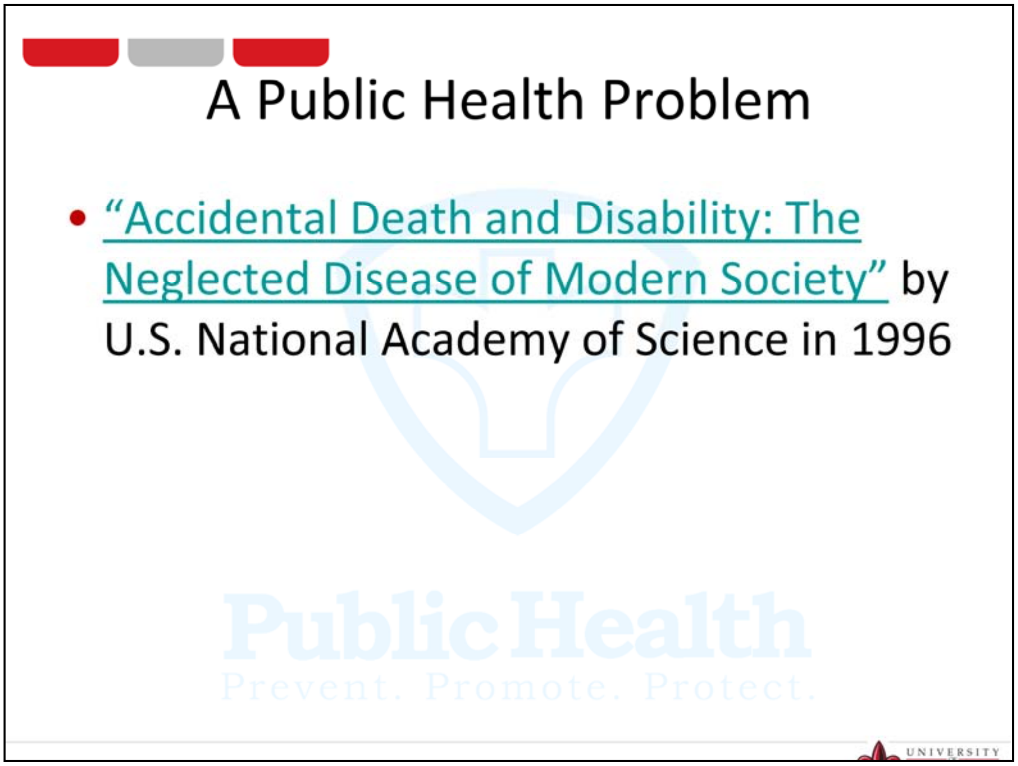
Do you know the numbers in your state?



How are we doing compared to other states? Not well at all. Because of the difference in population (more precisely, in number of licensed drivers) we compare rate, not absolute numbers.

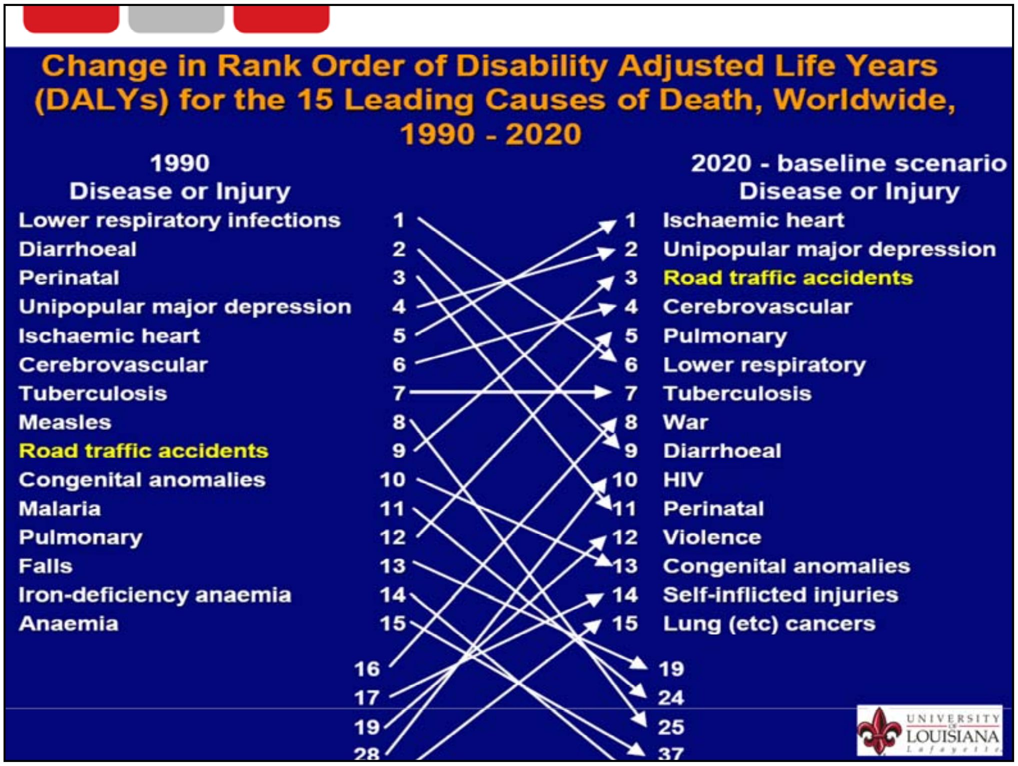
The bottom five states are: Montana, Louisiana, South Carolina, West Virginia, and Arkansas. Top five in lower fatality rate: Massachusetts, Connecticut, Minnesota, New Jersey and District of Columbia.

Ref 1:
http://www.census.gov/compendia/statab/cats/transportation/motor_vehicle_crashs_and_fatalities.html



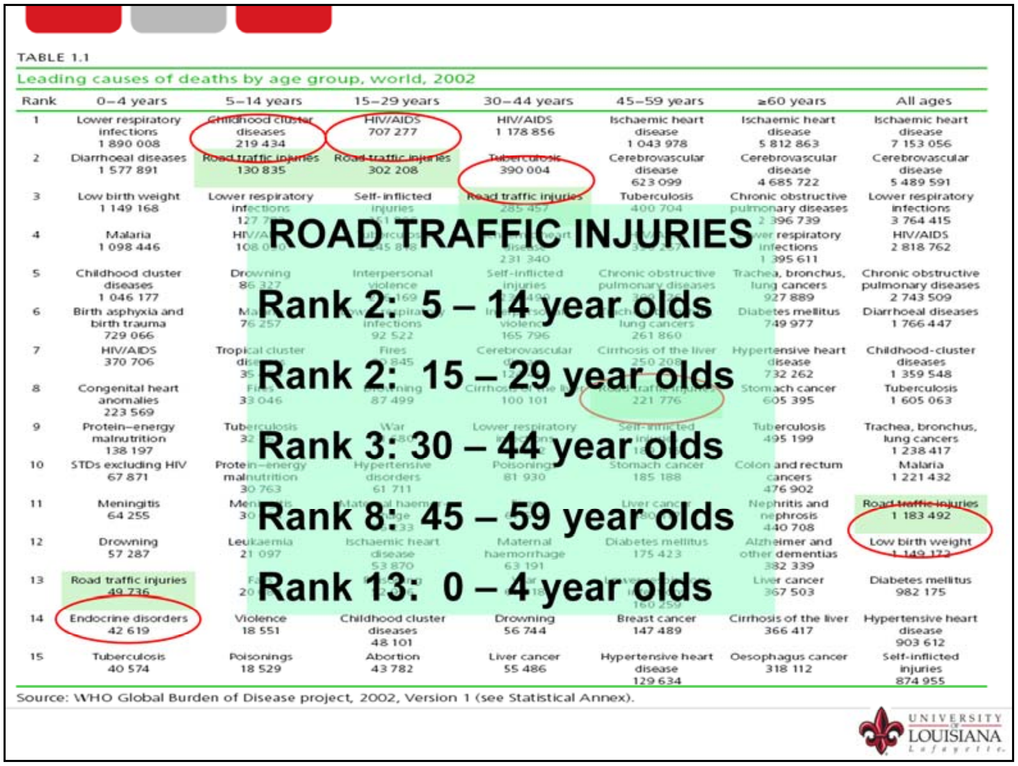
In 1990, road traffic crashes ranked 9th on the ten leading causes of death and disability in the world.

According to the World Heath Organization (WHO), by 2020, it is estimated that road traffic crashs will be the 3rd leading cause of death and disability.



With the advances made in medicine, lots of diseases are curable or will become curable. But….

Ref 1: http://grsp.drupalgardens.com/sites/grsp.drupalgardens.com/files/WHO%20tables.pdf



The table provides a global view of road casualties compared to other illnesses by age group. Public health experts are very concerned about the crash risk posed throughout the world. It is rapidly growing, especially in developing nations.

The Table shows in general, the driving risk for young people is extremely high, but older people experience less risk. This table depicts the public health view of road safety. Keep in mind, this is a global view. A similar map for the U.S. might look different. Can you see places where you think this might be the case? (Hint: the U.S. population is aging rapidly and the proportion of older people in the total population is rising. Crash risk for people over 75-80 is higher than any other age group except novice drivers.)

Deaths from Common Causes

Percent of Deaths of People over 65 years old

- Heart Disease – 95%
- Cancer – 88%
- Stroke – 96%
- Traffic Fatalities – 15%

Source: Center for Disease Control, 2009

The main thrust of medicine in the United States is to prevent and treat these three diseases and others which mainly effect the elderly.

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No discrimination towards age groups here (we will all get old sooner or later) just some facts.

Highway safety– a noble cause!

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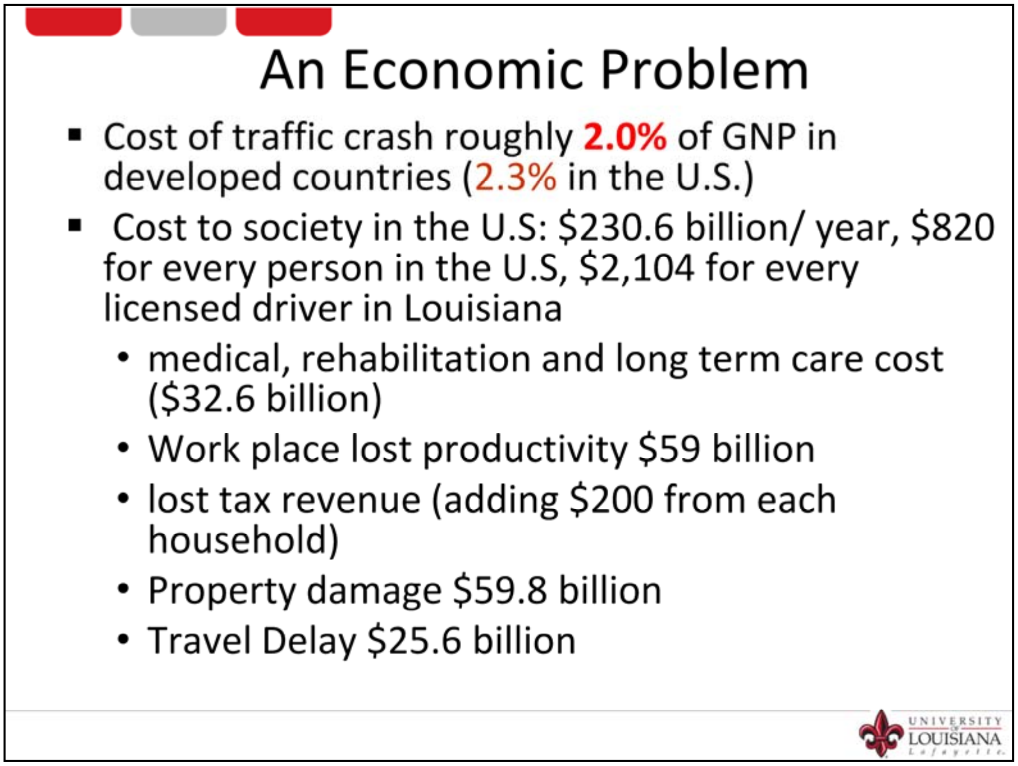
Highway safety– a noble cause!

The main goal for highway safety is to extend the lives of people, most of whom should have many more years on this earth. What we do and what we accomplish is **more** important in this sense than the work of most doctors. Improving highway safety is mostly to save young people.



Crash problem also hurts us economically.

Every 1 percent reduction will prevent 430 deaths and $2.3 billion annually in medical expenses and other losses from these collisions. Moreover, collisions are a leading cause of nonrecurring congestion. Collision prevention has added benefits in terms of reduced delay, fuel consumption, and emissions.

Ref : http://www.fiafoundation.org/Documents/Road%20Safety/counting the cost report.pdf

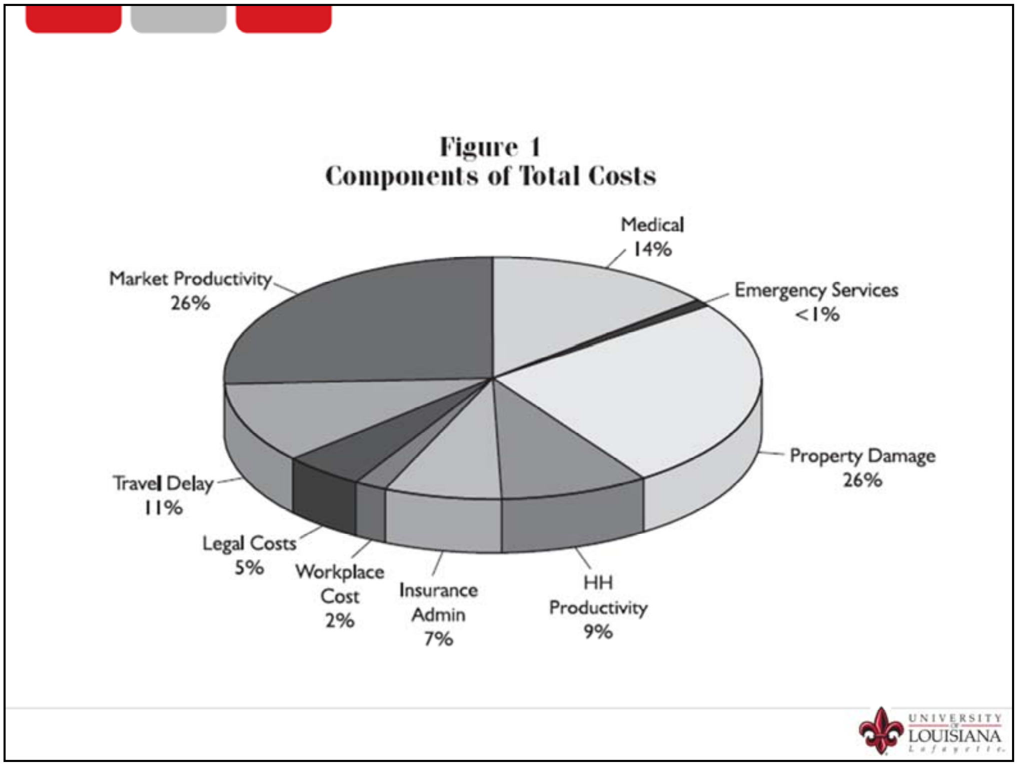


Figure 1
Components of Total Costs
Medical
14%
Emergency Services
<1%
Property Damage
26%
HH
Productivity
9%
Insurance
Admin
7%
Workplace
Cost
2%
Legal Costs
5%
Travel Delay
11%
Market Productivity
26%
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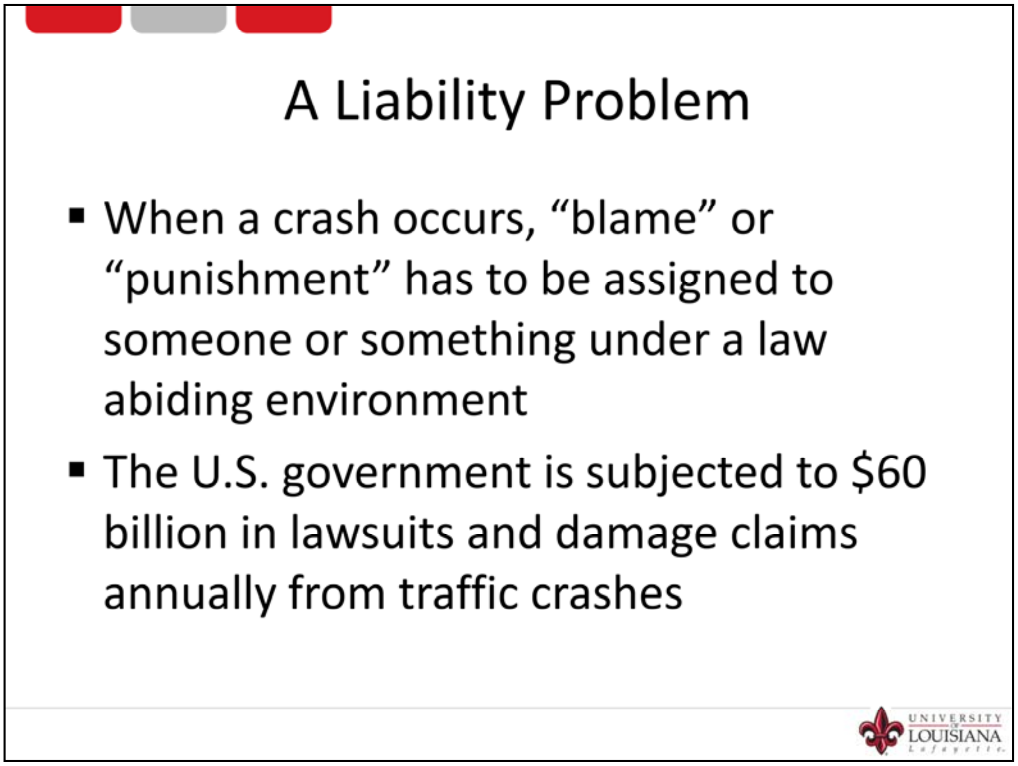

The crash problem also hurts governments at all levels directly and indirectly.

From lawyer's point of view

http://www.tsrinjurylaw.com/minnesota-highway-defect-attorney

"It is the government's responsibility to maintain public roadways, but unfortunately, highways are often neglected, and dangerous situations can result. Examples of highway defects that are capable of causing an crash include:

- Unmarked shoulder drop-off
- Potholes
- Uneven pavement
- Lack of signs
- Lack of guardrails
- Objects on the roadway
- Construction

When is the last time you saw the commercials made by injury attorneys?

Compensation asked by a lawsuit

- medical expenses
- lost wages
- pain and suffering
- other applicable damages

Huge compensations are demanded.

- Economic cost of vehicle crashes in Louisiana: $ 4 Billion per year http://www.resource4crashs.com/louisiana

What is the cost in your state?

A Grossly Underemphasized Problem

- In a **typical** month more Americans are killed by traffic crashes than were killed by the September 11, 2001 terrorist attacks.
- When 14 teenagers died in the 1999 Columbine high school shootings much of the U.S. population, led by President Clinton, grieved along with the victims' families. Yet more teenagers are killed on a **typical** day on the U.S. highways.

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By Evans, Leonard book “Traffic Safety” published August 2004.

U.S. no longer number one in the world in highway safety

Prior to the mid 1960s the U.S. highway system was the safest in the world measured by traffic fatalities per registered vehicles or per distance traveled. In this century, the U.S has dropped from the first place into the sixteenth place behind many developed countries such as Australia, Canada, Denmark, Finland, Germany, and Great Britain.

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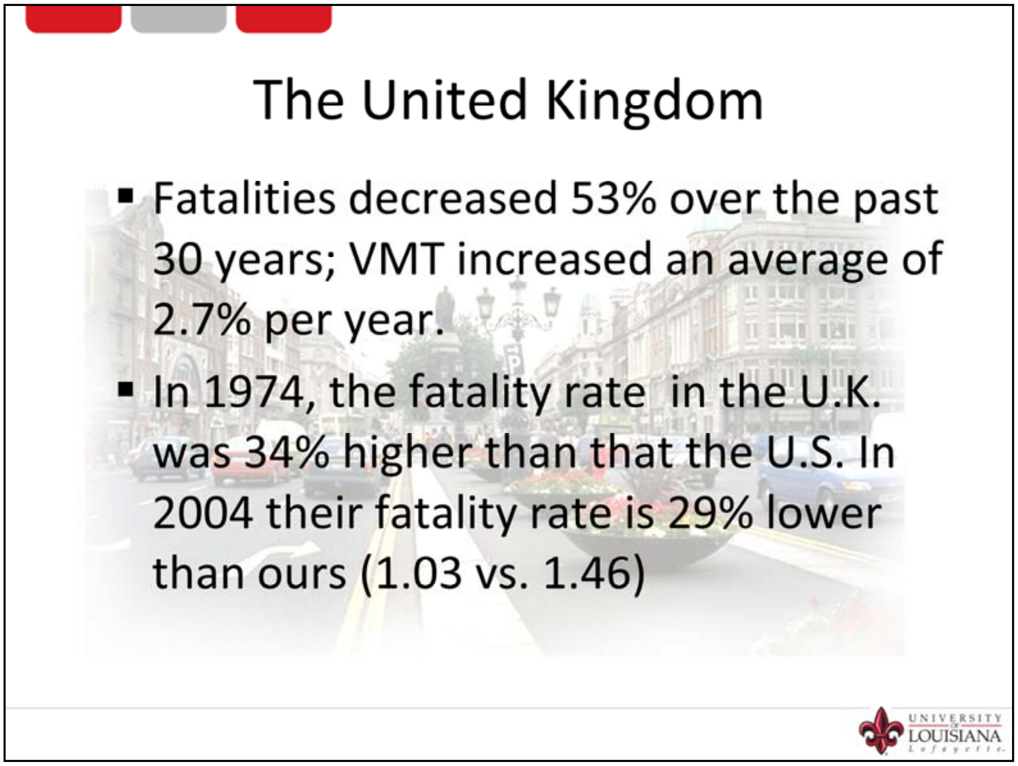
It is worthwhile to know that U.S. has lost its number one status in roadway safety.

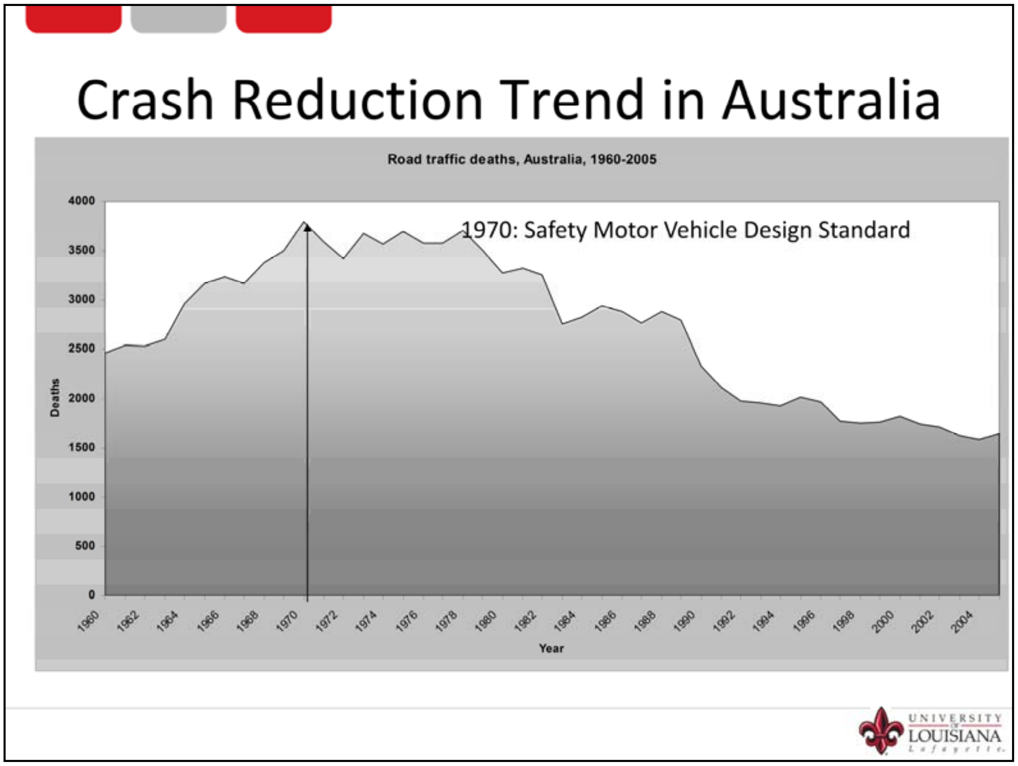


How do other leading countries do in reducing roadway safety?

Ref : http://www.ltrc.lsu.edu/tec_07/presentations/highway.pdf

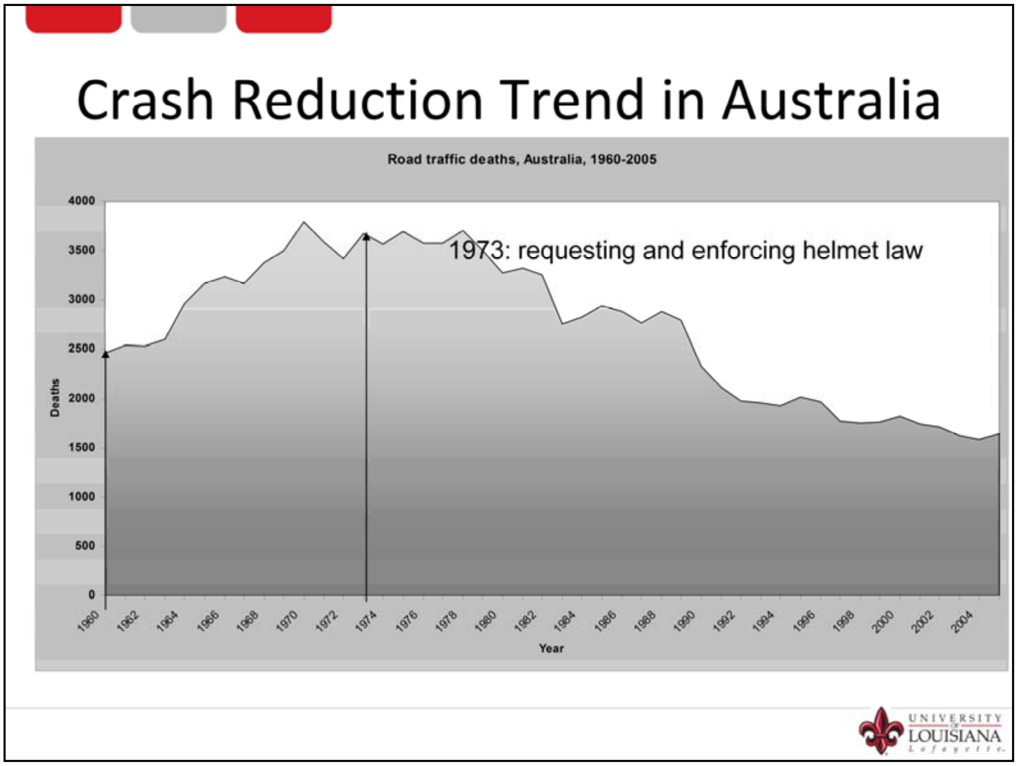
What do we do in these areas?

Ref 1: http://www.wbtw.com/story/22810618/survey-finds-seat-belt-use-up-in-south-carolina



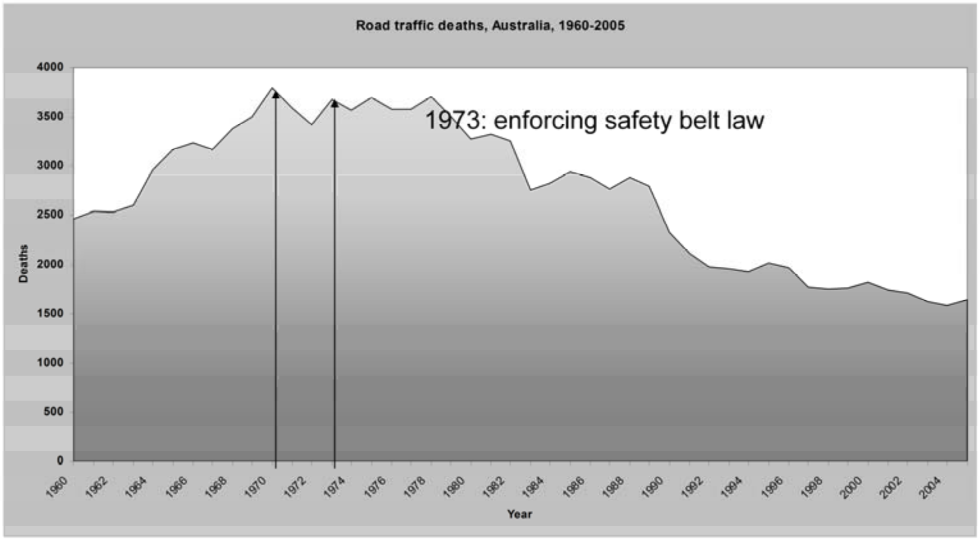
Australia

- Vehicle design standards 1970 (i.e., mandatory fitting of seatbelts) Seatbelts 1973
- Motorcycle helmets 1973
- Random breath testing 1976-1988 all Australian states introduced mandatory random breath testing
- Bicycle helmets 1990-1992
- Safer roads through the Federal “Blackspot program”
- Introduction of improved enforcement technologies (speed cameras, red light cameras and radar “guns”)

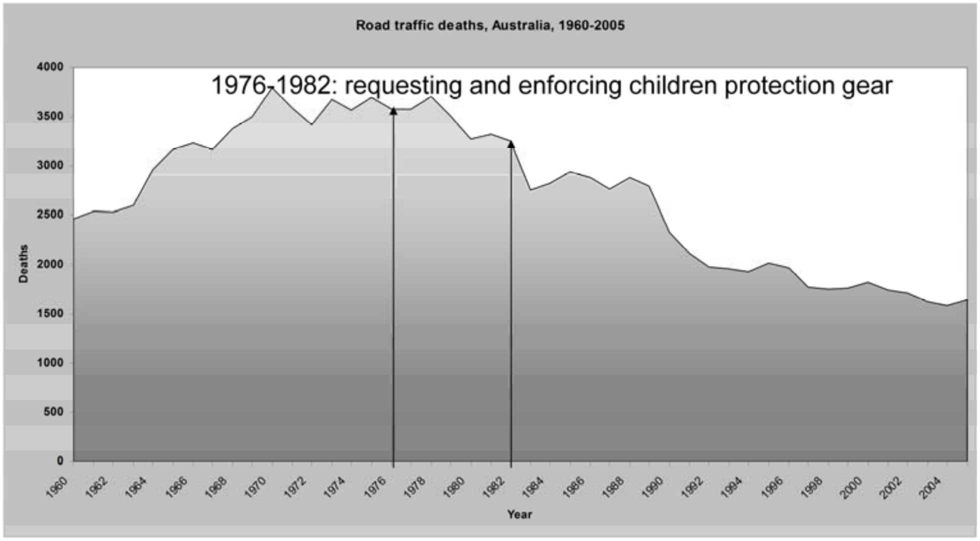


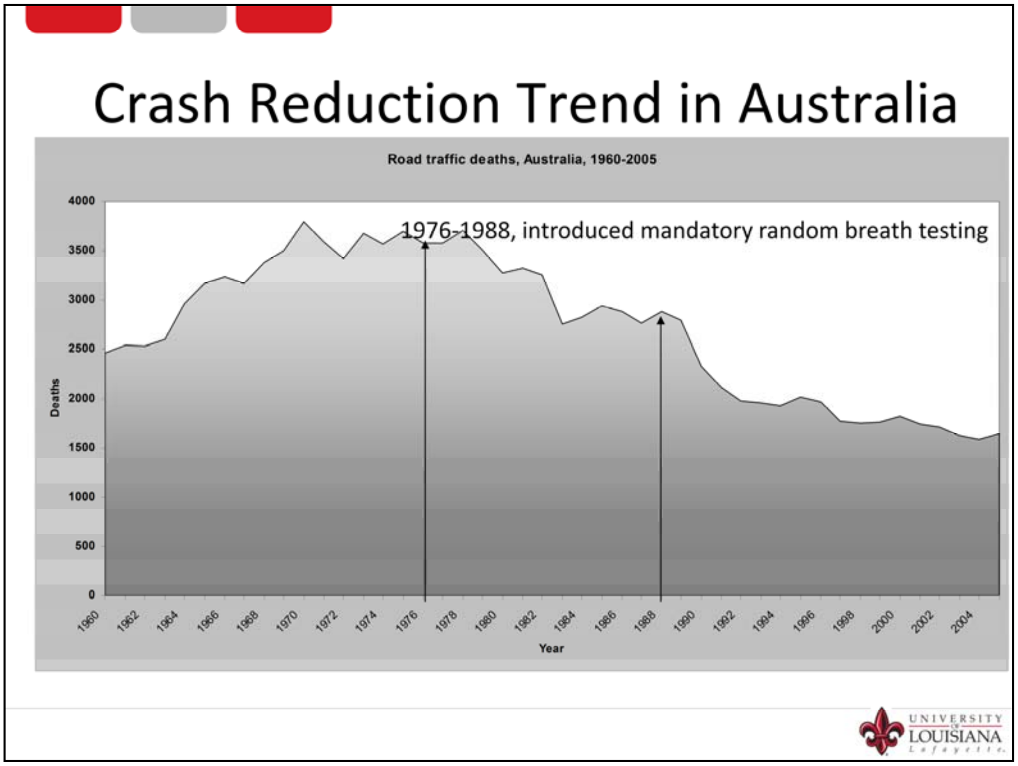
Effective policy (or regulation) makes a difference.

Crash Reduction Trend in Australia

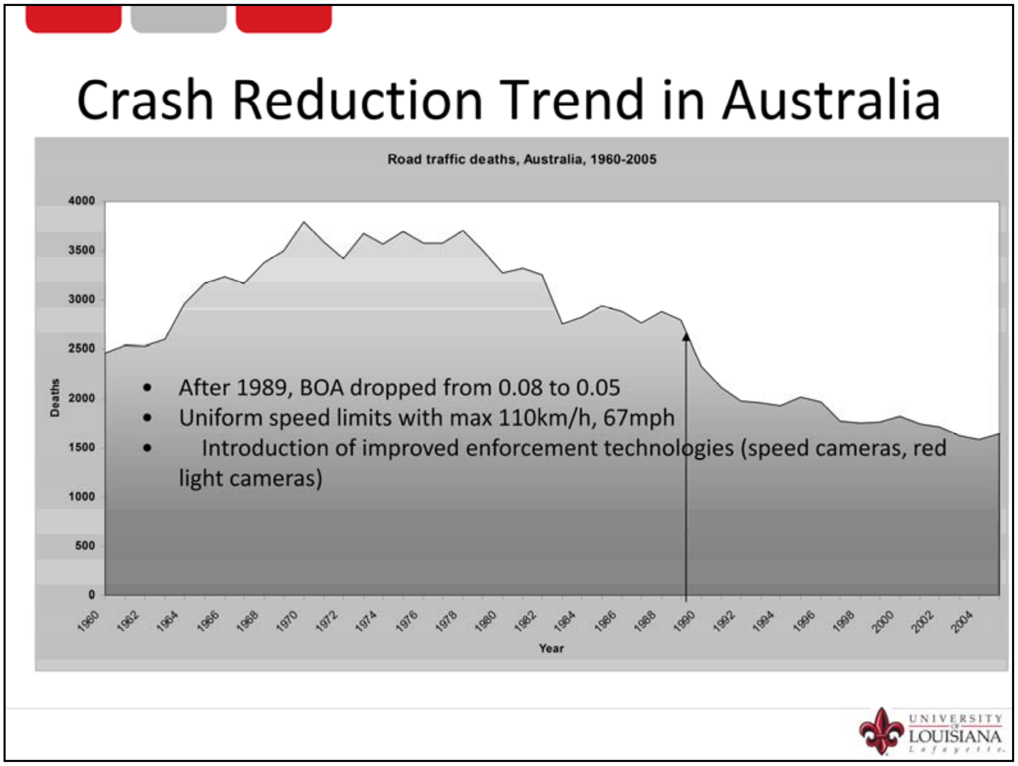


Crash Reduction Trend in Australia





All Australian states introduced mandatory random breath testing in 1976-1988.



- Safer roads through the Federal “Blackspot program”
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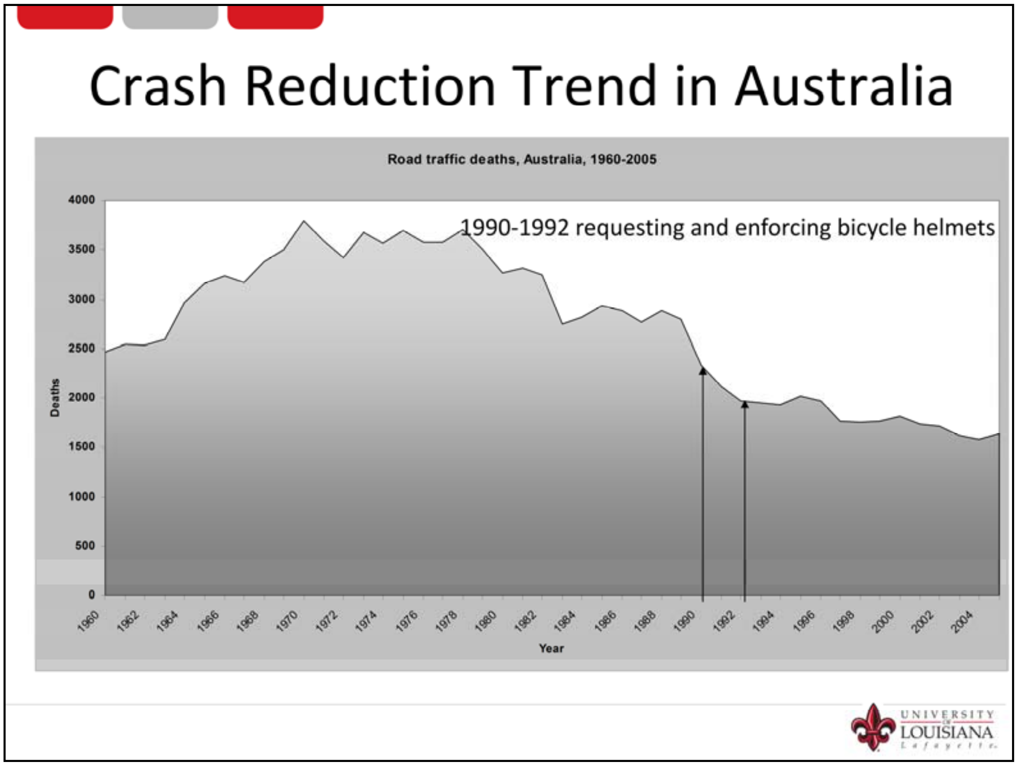
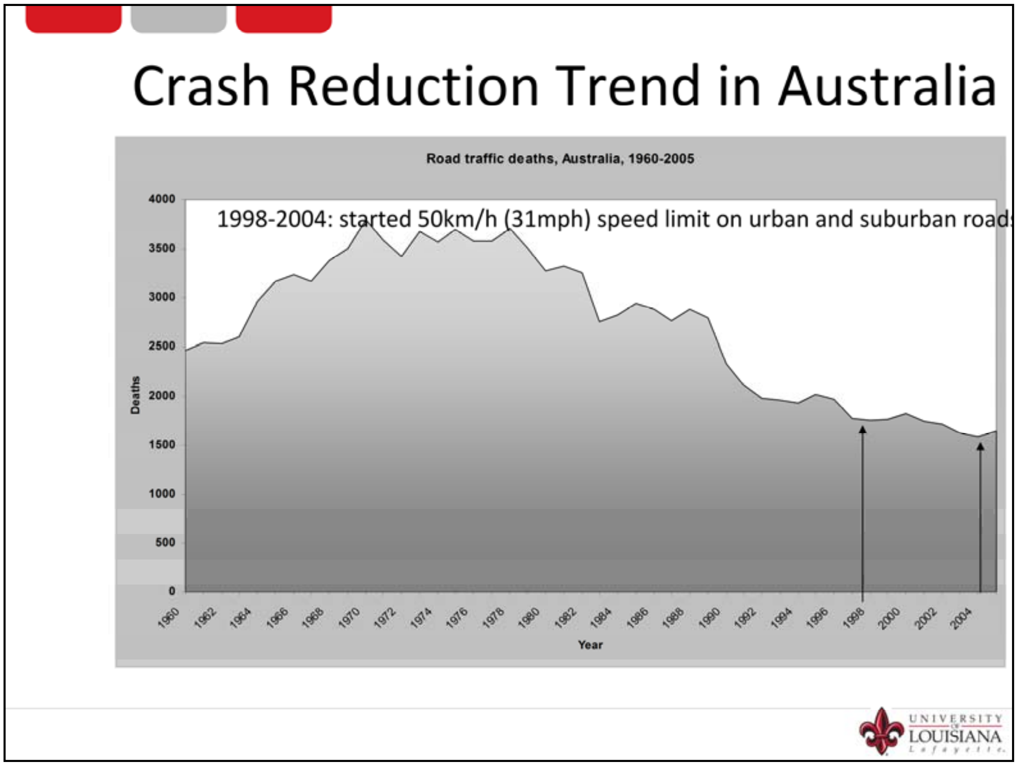


Bicycle helmets were enforced in 1990-1992.



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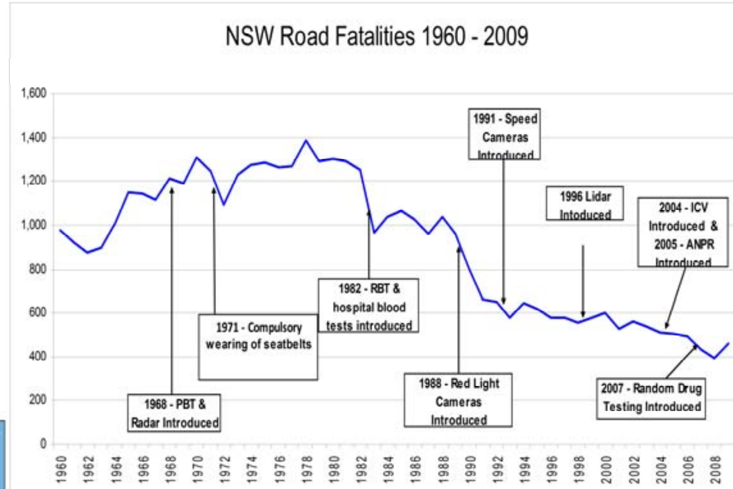
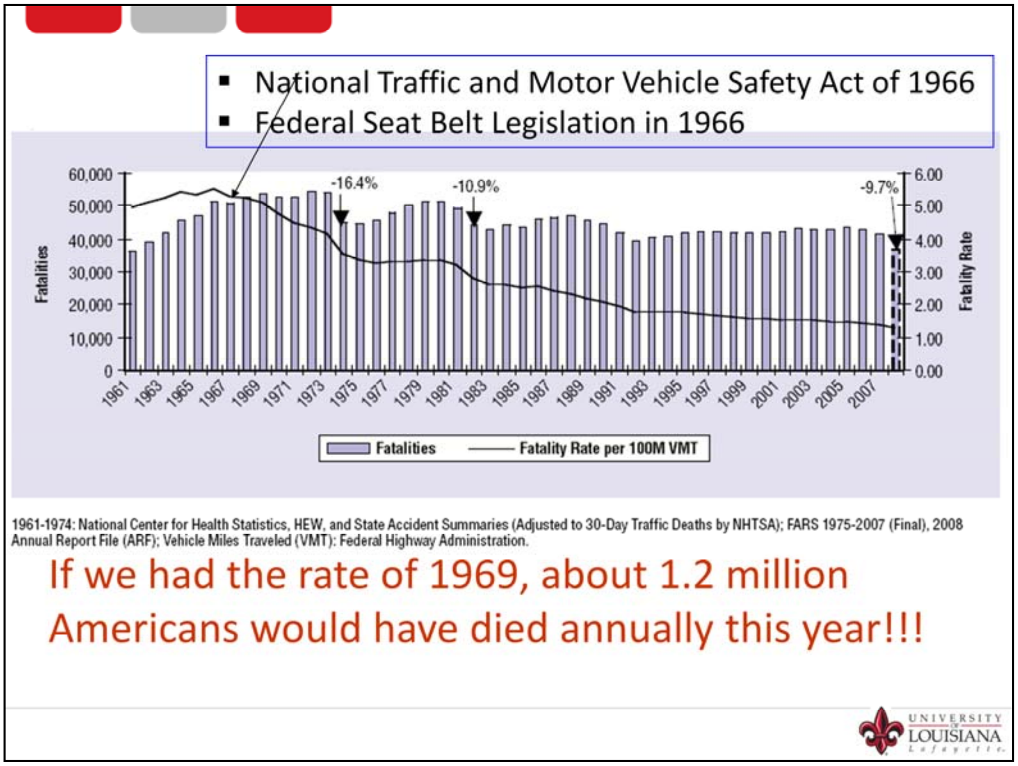


New South Wales, Australia



Although the U.S. is not number one on the world on roadway safety, great progress has been made in the last 50 years. It is just not enough!

Ref 1: http://www.nhtsa.gov/FARS

Road Safety a National Priority

- American Association of State Highway and Transportation Officials, and Governor's Highway Safety Association **Cut fatalities in half by 2020!**

- LA Strategic Highway Safety Plan: Destination Zero Deaths

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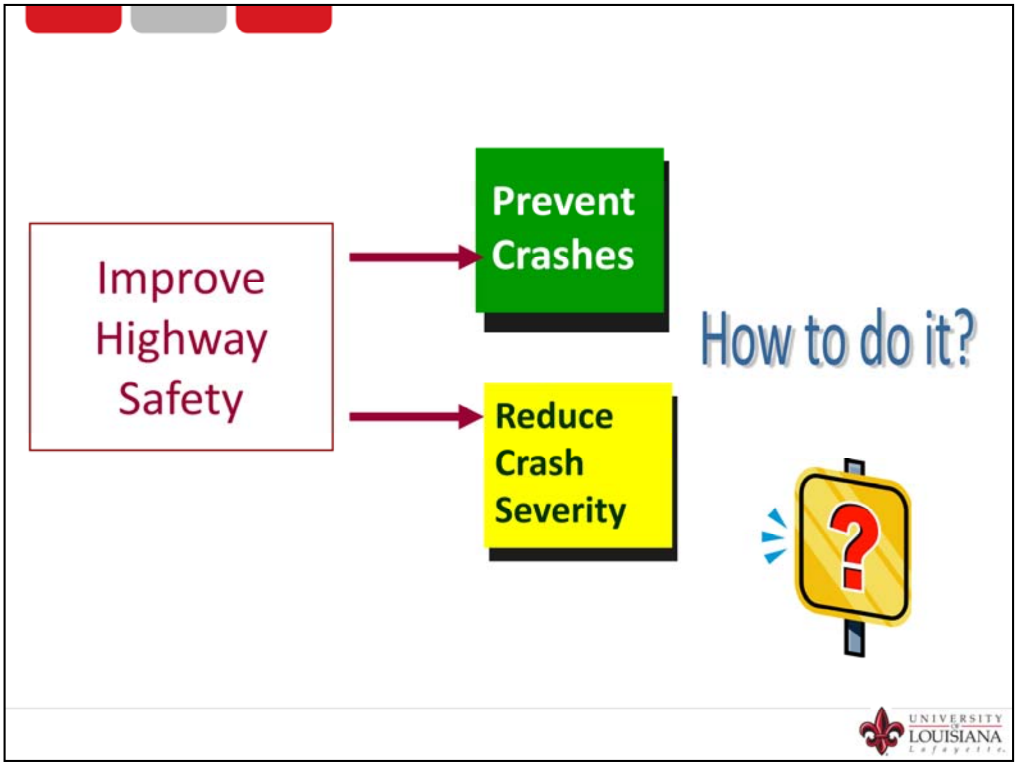
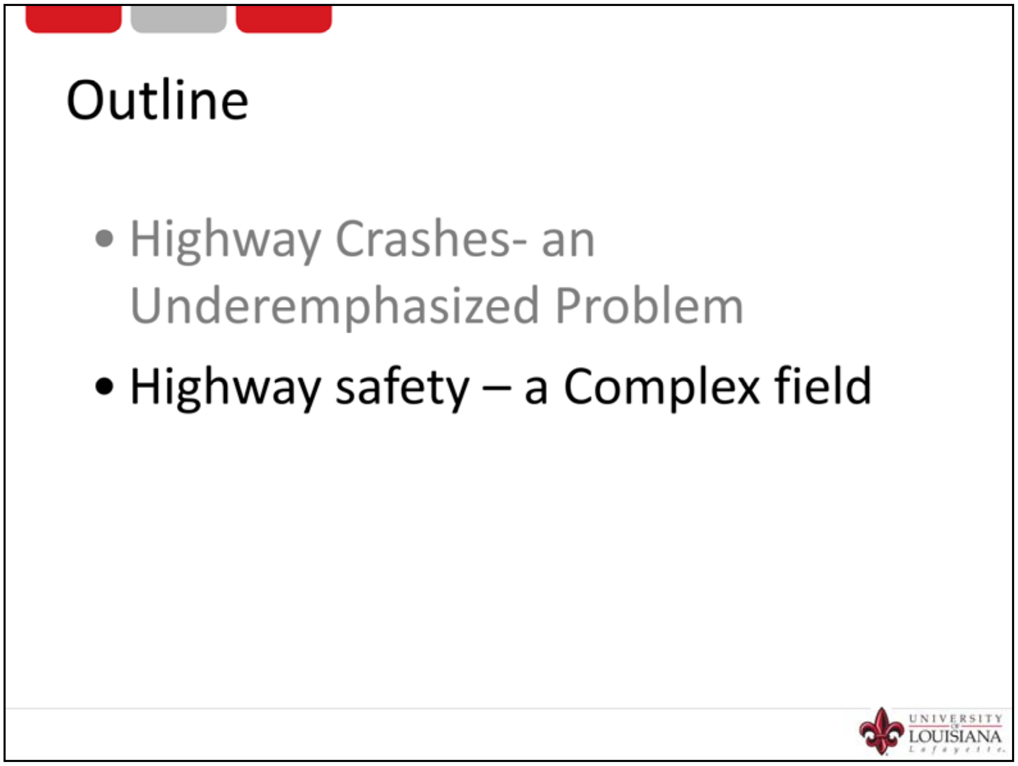
The leadership has fully recognized the problem.

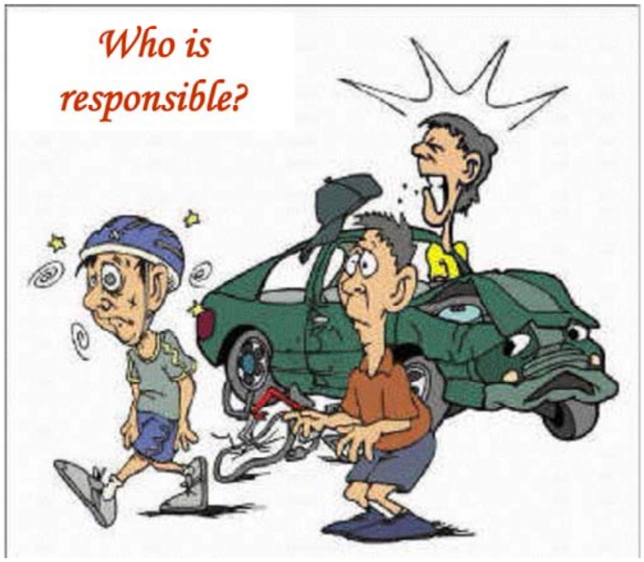


It is one thing to set up goals; it is another to have tangible means to achieve the goals.

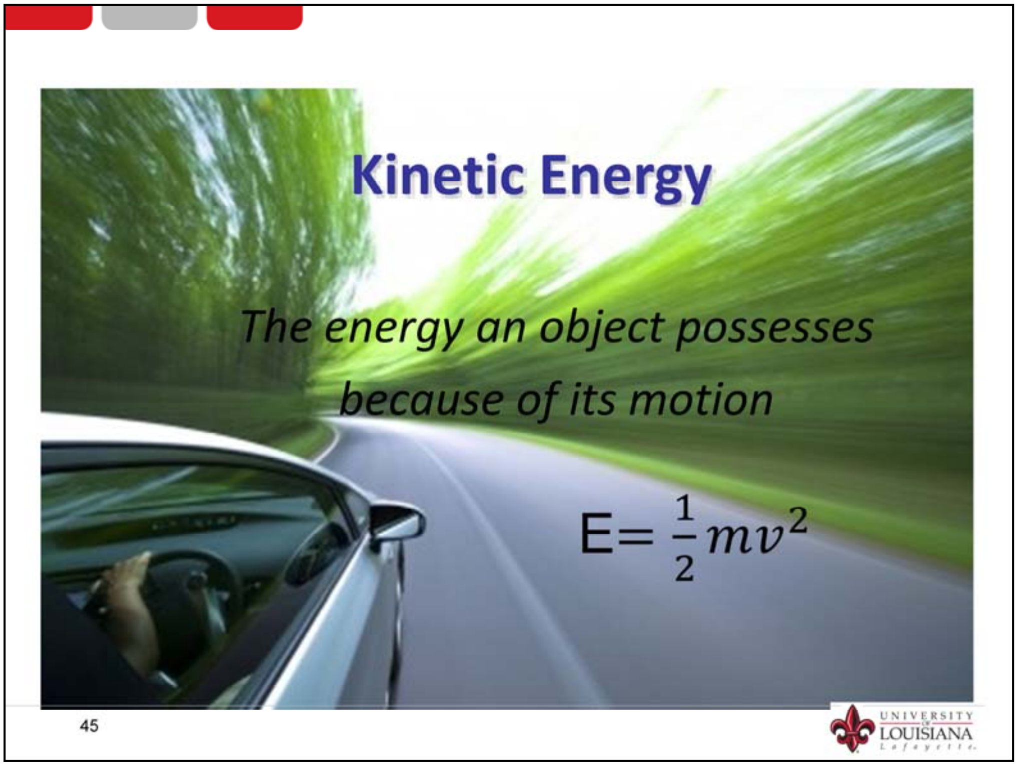


Before discussing the concrete actions to reduce crashes, let’s talk about the complexity of roadway safety.

Who is at fault?

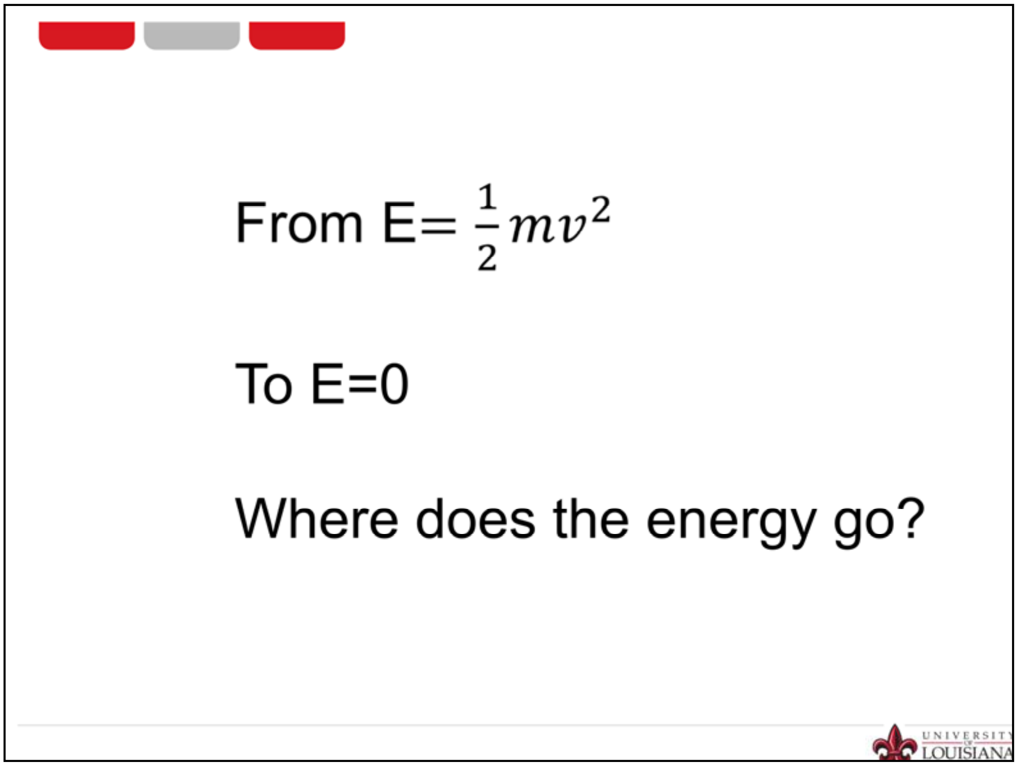


It is common to blame someone or something for a crash.



Crashes occur when bodies (entire vehicle, occupants, baggage, etc.) in motion collide. Three stages occur in most crashes. First, the vehicle hits something; second, the occupants hit the inside of the vehicle; and finally, internal organs slam against the skeletal structure.

The forces and energy involved in crashes can become quite extreme. Analyzing the forces in a motor vehicle crash is a complex undertaking. When a car is traveling along a road it has a certain amount of energy, called kinetic (motion) energy. In normal driving, kinetic energy is converted to heat through braking (brake pads to rotors and rubber to pavement). In fact, normal driving is a repetitive exercise of converting kinetic energy to heat. In a motor vehicle crash, kinetic energy is converted to heat (tires, metal, etc.), friction losses (tires, scraping, etc.), and crush energy (deformation of car and human parts).



The scope of this workshop will not cover the equations involved in calculating crash energy but consider one example. If a 3000-lb. car is traveling at 60 mph (88 ft/sec) and collides with a solid wall, what is the crush depth of the vehicle (assume wall does not crush at all)? The answer is the car must be crushed 4.9 ft. to convert all of the kinetic energy to crush energy. Hopefully, the car is designed to sustain 4.9 ft. of crush damage without harming the occupants.

Suppose that the driver was able to reduce speed by 20 mph by applying the brakes prior to impact (converting some of the kinetic energy to heat energy), what would the crash depth in this scenario? The crash damage is substantially less as a result of applying the brakes. This outcome may represent the difference between being killed and walking away from the crash unharmed. Some important concepts related to crash dynamics are:

• Kinetic energy of motion is converted to heat, friction, and crush damage.

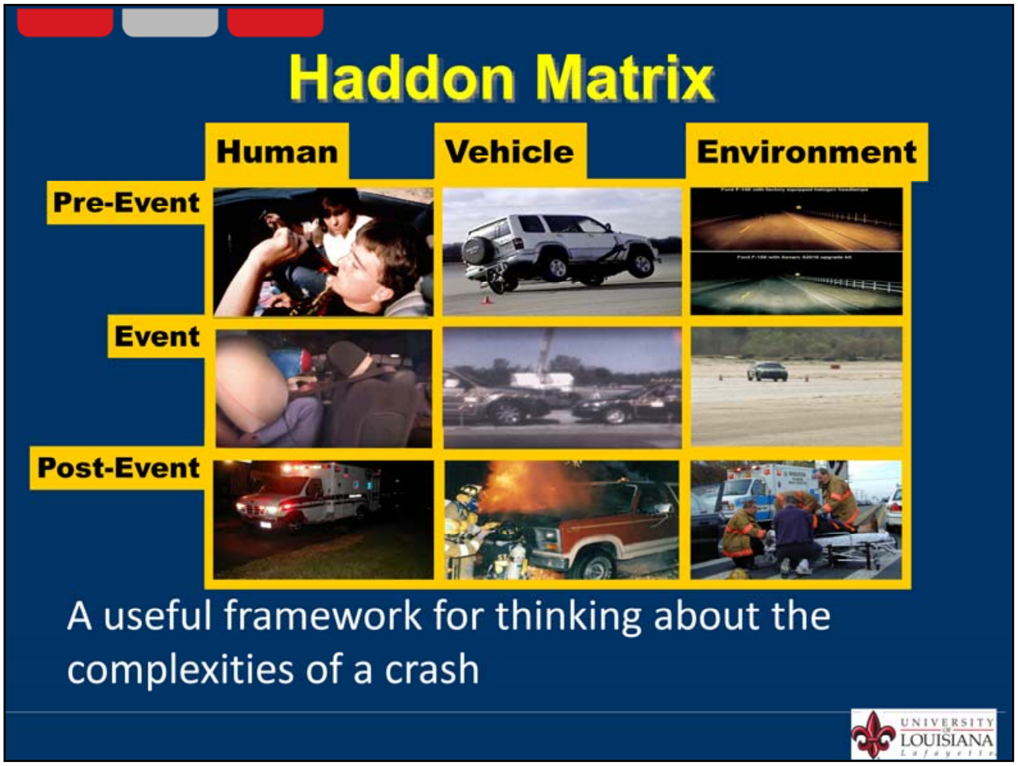
• Converting kinetic energy to heat through braking represents normal driving.

• Crash “survivability” is related to how energy is absorbed by the vehicle and passengers.

• In general the smaller the energy and the greater the time permitted to absorb the energy, the more survivable the crash.

Some important concepts related to crash dynamics

- Kinetic energy of motion is converted to heat, friction, and crush damage.
- Converting kinetic energy to heat through braking represents normal driving.
- Crash “survivability” is related to how energy is absorbed by the vehicle and passengers.
- In general the smaller the energy and the greater the time permitted to absorb the energy, the more survivable the crash.



Let’s “dissect” a crash

Dr. William Haddon was an epidemiologist, who is credited with first describing the highway safety challenge in terms of how the medical profession would approach a disease –

- how to prevent it from happening
- how to treat it while it’s happening; to reduce severity
- how to recover after the event.

AND…, you should look at key elements affecting the problem; in this case, what are the relationships among the person, the vehicle, and the environment (esp. including roadway features).

He became the first Director of the organization which would become NHTSA.

The USDOT works in <u>ALL</u> areas of this matrix.

Ref 1: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1228774/

A Study Case

Driver A was approaching a traffic signal and stopped abruptly when the light changed to yellow. Driver B, who was behind, did not manage to stop in time. A rear-end collision occurred.

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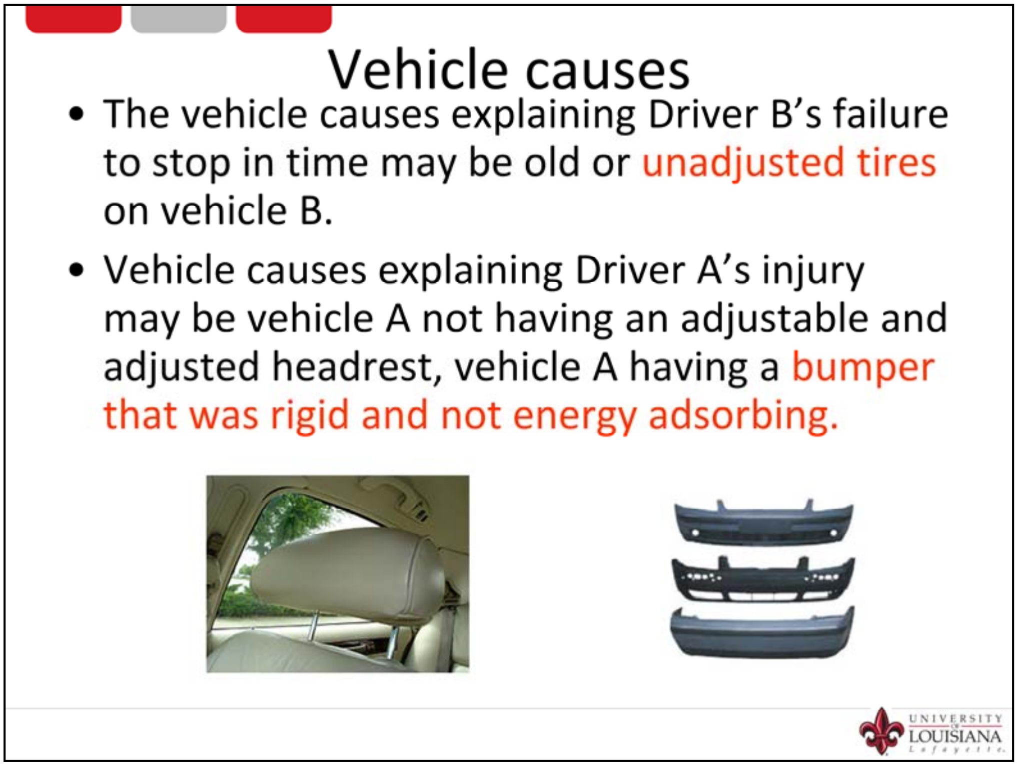
For example, an crash occurred under the following circumstances: Driver A was approaching a traffic signal and stopped abruptly when the light changed to yellow. Driver B, who was in the following vehicle, did not manage to stop in time. A rear-end collision occurred and Driver A received a whiplash injury. Many possible causes can be ascribed to this simple story. A police officer might record “following too close” as the cause but this is a restatement of what occurred and does not lead to interventions.

Human causes

- The human causes explaining the delayed reaction by Driver B may be:
  1. cognitive deficiencies that go with advanced age
  2. distraction by cell phone use
  3. influence of alcohol
  4. conversation with passengers,
  5. fatigue, or inattention.

Driver B's failure to stop in time is also related to the abruptness of the action by Driver A. The human causes explaining the unexpected or hard braking of Driver A may be: bad judgment, impaired cognitive skills, deficient driving habits, distraction, or a truck preventing a clear view of the signal.

Ref : http://www.ite.org/Membersonly/techconference/2008/CB08C2002.pdf



The auto headrest was invented and designed by a man in Arcadia, California, G. J. Schifano, in the mid 1950s, when his doctor was telling him about the alarmingly increased numbers of whiplash patients he was seeing. Headrests started to appear as an option on American cars in the late 1960s. Headrests were required by NHTSA in all cars sold in the US, effective January 1, 1969.

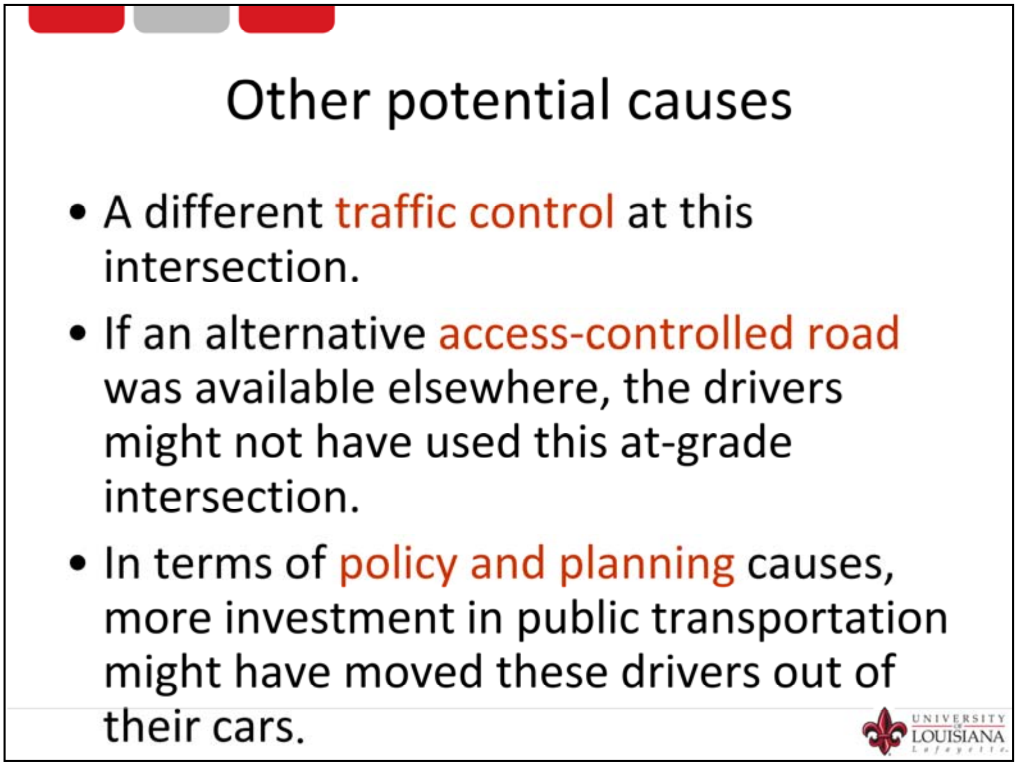
Today, most headrests are cushioned for comfort, are height adjustable and most commonly finished in the same material as the rest of the seat, as seen in the picture to the right.

Headrests are provided for comfort and safety. They are designed to prevent the backlash movement of the occupant's head should a collision occur. This, in turn, can prevent potentially fatal whiplash neck injuries.

When travelling in an automobile, a properly adjusted headrest can reduce the severity of the neck injury. The top of the headrest should be in line with the top of the occupant's head.

Environmental causes

- The environmental causes explaining the crash could include wet pavement, a polished roadway surface with reduced surface friction, a steep downgrade, or a signal phasing which result in a 'dilemma zone.'



A different traffic control at this intersection such as a stop sign or roundabout could have changed the outcome.

If an alternative access-controlled road was available elsewhere, the drivers might not have used this at-grade intersection.

In terms of policy and planning causes, more investment in public transportation might have moved these drivers out of their cars.

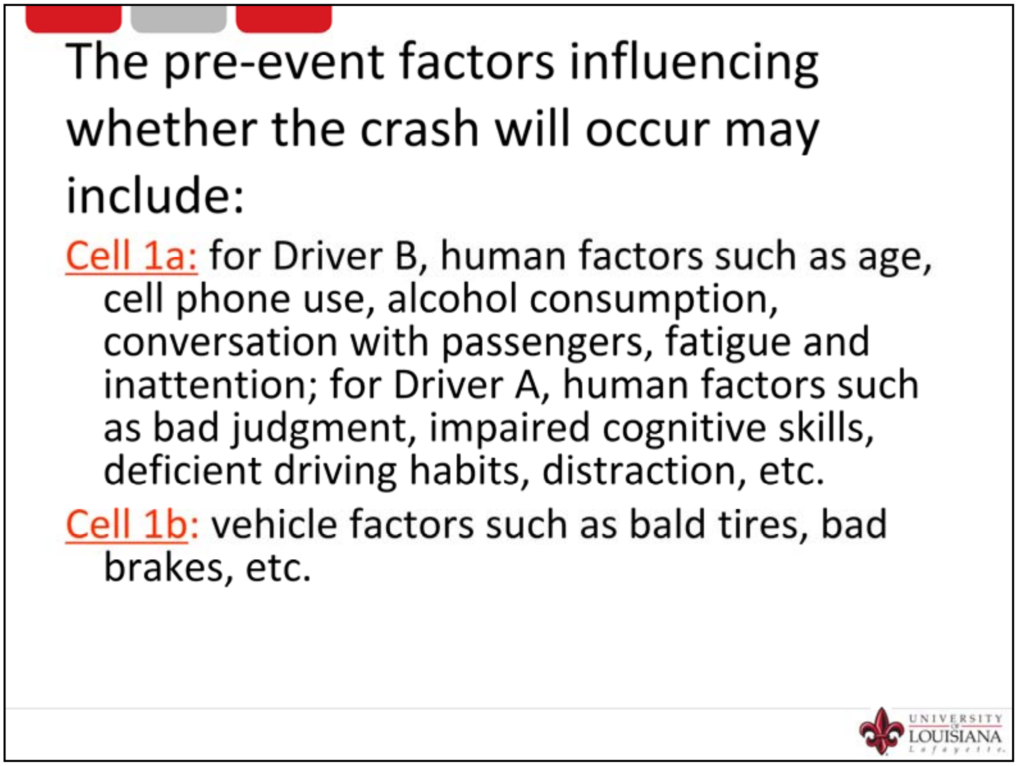
- All these factors, and others, may be causes of the crash and each may lead to possible treatments.
- If any one of these causes had been different, the outcome might have changed.

Learning about crash causes assists in the planning, design, and maintenance of infrastructure, and in the management of the overall highway system, both of which include the selection of treatments for crash prevention and the reduction of crash consequences.

Dissecting a Crash

	Human	Vehicle	Roadway and other factors
Pre-crash will the crash occur?	1a	1b	1c
Crash How severe will it be	2a	2b	2c
Post-crash What will be the outcome?	3a	3b	3c

For example, the rear-end crash described previously illustrates the use and usefulness of the Haddon Matrix in the following slides.



Ref : http://www.ite.org/Membersonly/techconference/2008/CB08C2002.pdf

Cell 1c: Physical environment factors such as wet pavement, polished aggregate, steep downgrade, badly coordinated signal system, etc. Social environment factors such as cultural norms, laws, regulations and enforcement that determine alcohol use, use of cell phones while driving, consideration of safety in signal timing and coordination, etc.

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The event factors influencing the severity of damage and injury once an crash has occurred may include:

Cell 2a: human factors such as vulnerability to injury, e.g., age, failure to wear a seat belt, etc.

Cell 2b: vehicle factors such as bumper heights and energy adsorption, headrest design, airbag operations, etc.

Cell 2c: physical environment factors such pavement friction and grade social environment factors such as regulations that govern vehicle design and the factors in Cell 2b

The post-event factors influencing the outcome after the initial damage and injury have occurred may include:

- Cell 3a: human factors such as age and gender
- Cell 2b: vehicle factors such as ease of removal of injured passengers, etc
- Cell 3c: physical factors such as the time and quality of the emergency response and subsequent medical treatment

This example shows how the Haddon Matrix assists in creating order when thinking about crash causes. The Haddon Matrix also allows for the orderly consideration of which treatments may apply to which factor or cause and crash phase. The effect of treatments or interventions is discussed in the next section.

Cell 3c: social environment factors such as funding and policy decisions, prevailing medical insurance system, inclination to complain of injury, litigiousness, etc.

Now, let's do an exercise on a "T-Bone" collision at intersection.

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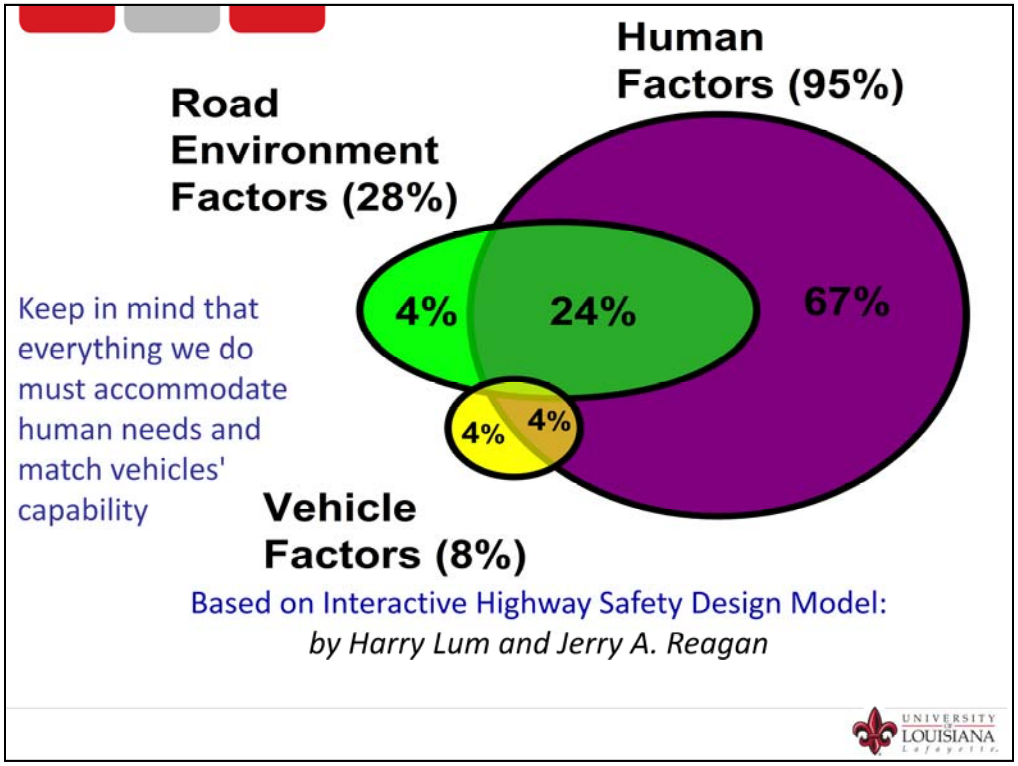
Crash is not an accident, it is preventable. Crash reduction can not happen by chance.

Source: Safer Roads: A Guide to Road Safety Engineering by K.W. Ogden. Ashgate

Not all distracted drivers, unforgiving roadside designs, vehicle mechanical problems result in crashes. A severe crash occurs when all risky situations come together. To prevent crashes, we need to build strong defense system (layers)

- Need to understand characteristics of all components of the system and interactions between the components

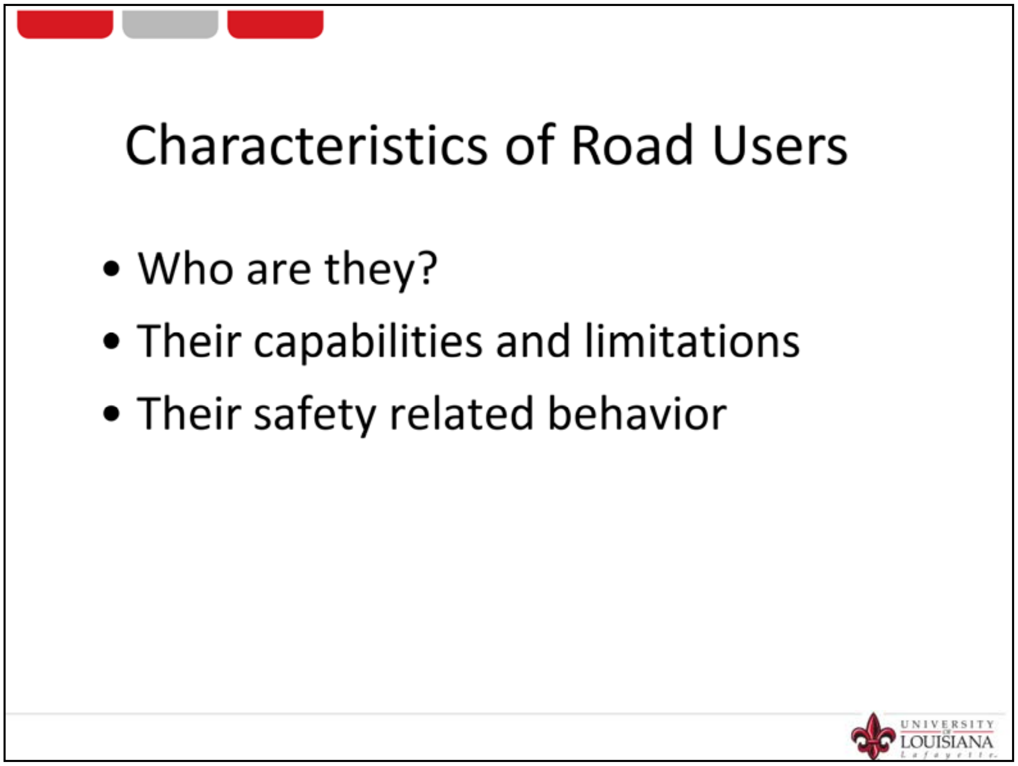


Understanding motor vehicle crashes and contributing crash factors requires a multidisciplinary perspective. Applying a broad perspective to motor vehicle crashes is difficult due to the compartmentalization that naturally occurs. Departments of transportation (local, state, federal) are responsible for roadway countermeasures, while behavioral countermeasures are often considered by health agencies, the medical and insurance communities, state highway safety offices, motor carrier safety representatives, and advocacy groups. So although a multi-disciplinary approach is desired, it is often difficult to achieve. The graphic on this slide shows the interaction effect. For example, 24 percent of crashes involve factors associated with both the roadway and road user behavior.

The figure presents some findings from a study that compares causes of crashes in the United States and Great Britain. This study notes that only 3 percent of crashes are due solely to the roadway environment, 57 percent solely to drivers, 2 percent solely to vehicles, 27 percent to the interaction between road environment and drivers, and 3 percent to the interaction of the environment-driver vehicle. Taken at face value, this suggest that road-related elements are associated with 34 percent of crash causation (or 40% by another account). Consequently, a perfect model would attribute about 34 percent of R^2 to the roadway road variables, including the driver and the vehicle. Recent work in this area looks at an alternative methods of evaluating the effects of the driver and the traffic. One obvious question is: Why not go directly to phase 3? There are three reasons. While there are traffic models that could (and will be) adapted to IHSDM, there is no appropriate driver module. The analysis and simulation techniques have not been developed. Finally, the crash relations from phase 2 may be needed.

Road safety is a complex and interdisciplinary field

It is time to introduce this complex system.



First, let's start discussion on users– the component with souls and personalities.

Who are they?

- Wide range of system users
- What range of drivers use the system?
  - Ages: 16 year old to 80 year old
  - Different mental and physical states
  - Physical limitations (sight, hearing, etc)
  - experience
- Design Driver: driver most expected to use facility (familiar or unfamiliar?)

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Users are highly diversified in several aspects.

Age distribution of drivers

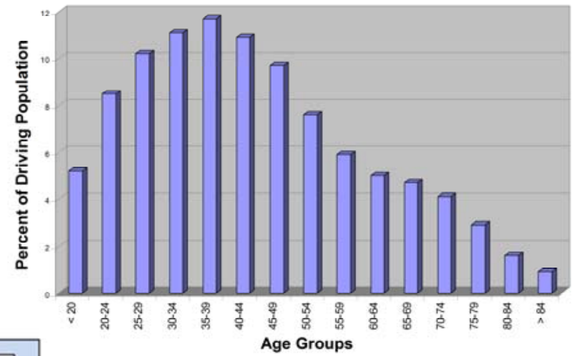
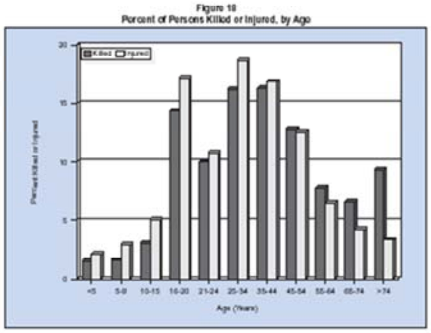
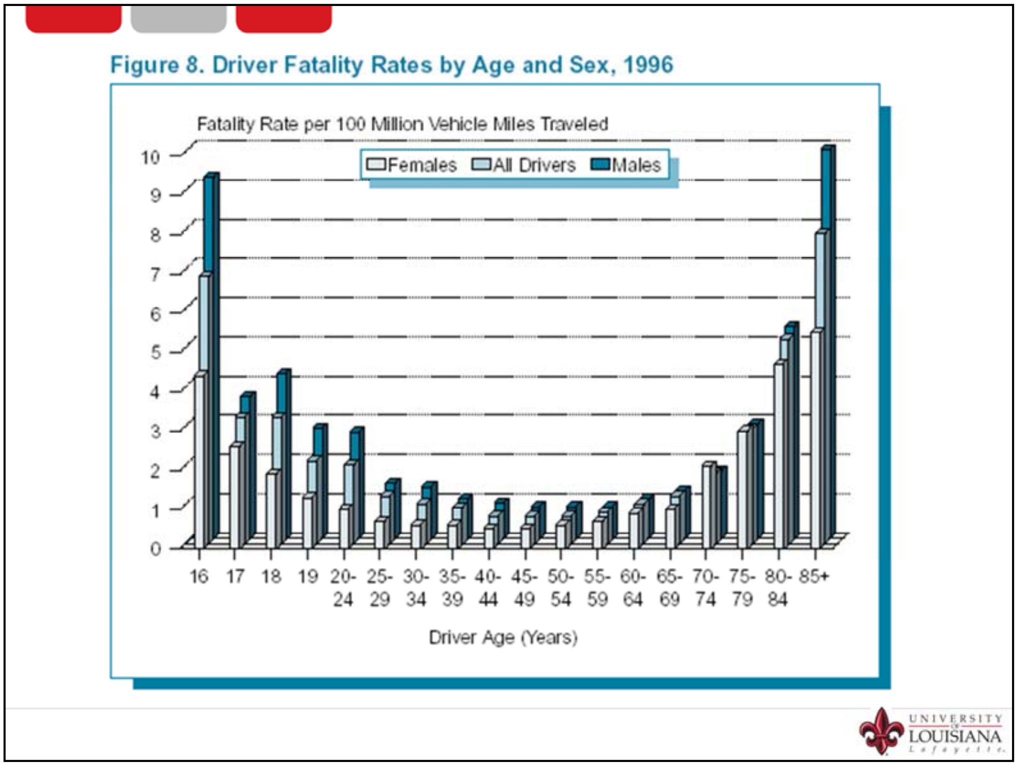


Figure 18
Percent of Persons Killed or Injured, by Age

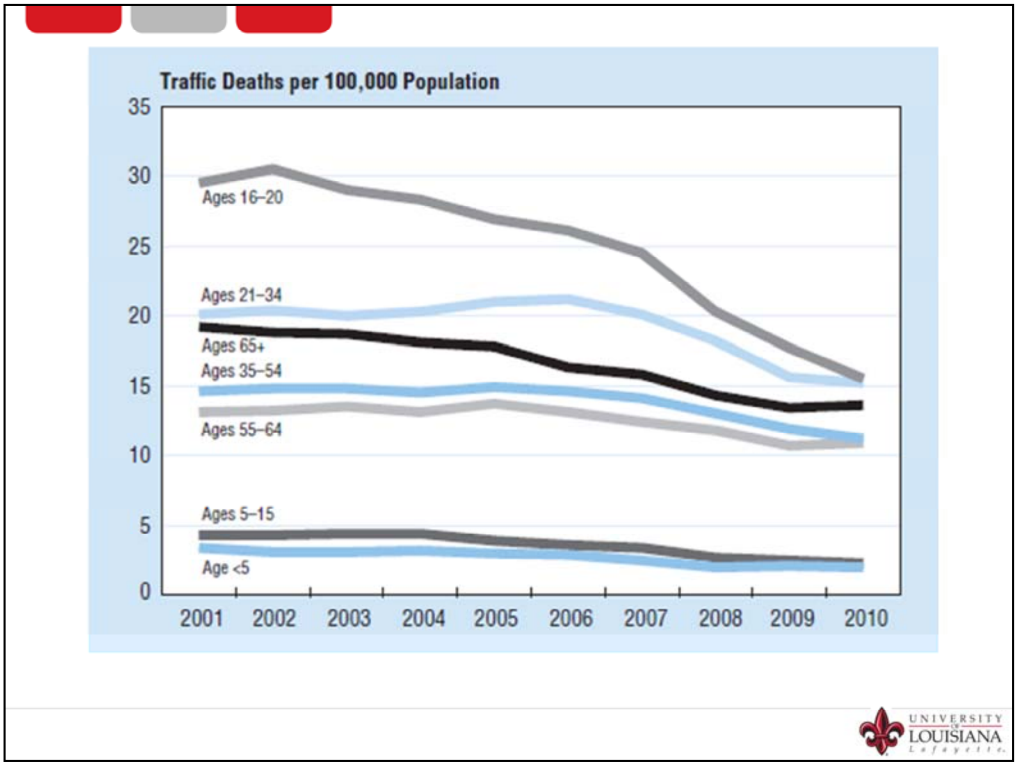


Source – FHWA Crash Facts Book

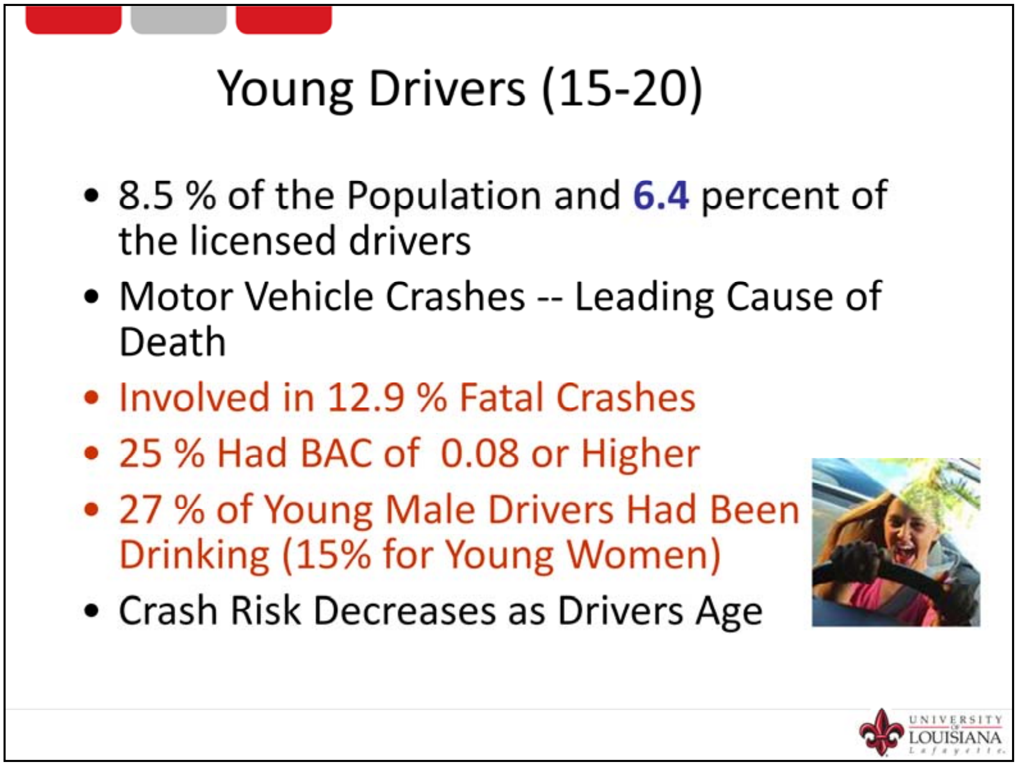
Age



Crash rate by age reveals better information.

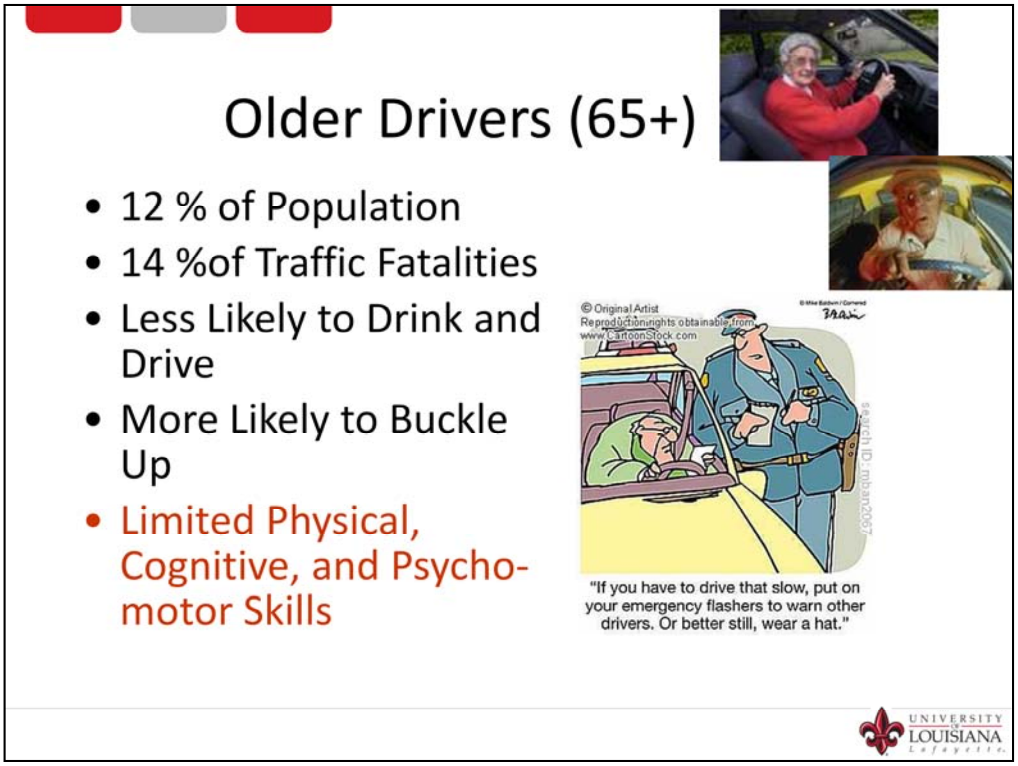


Which group has the most significant improvement? What does that mean?



Motor vehicle crashes are the leading cause of death for 15-to-20 year-olds (based on 2004 figures, which are the latest mortality data available). In 2006, 3,490 15-to20-year-old drivers were killed and an additional 272,000 were injured in motor vehicle crashes; 12.9 percent of all the drivers involved in fatal crashes were between 15 and 20 years old and 16 percent of all drivers involved in police-reported crashes were young drivers; while they represented only 8.5 percent of the population.

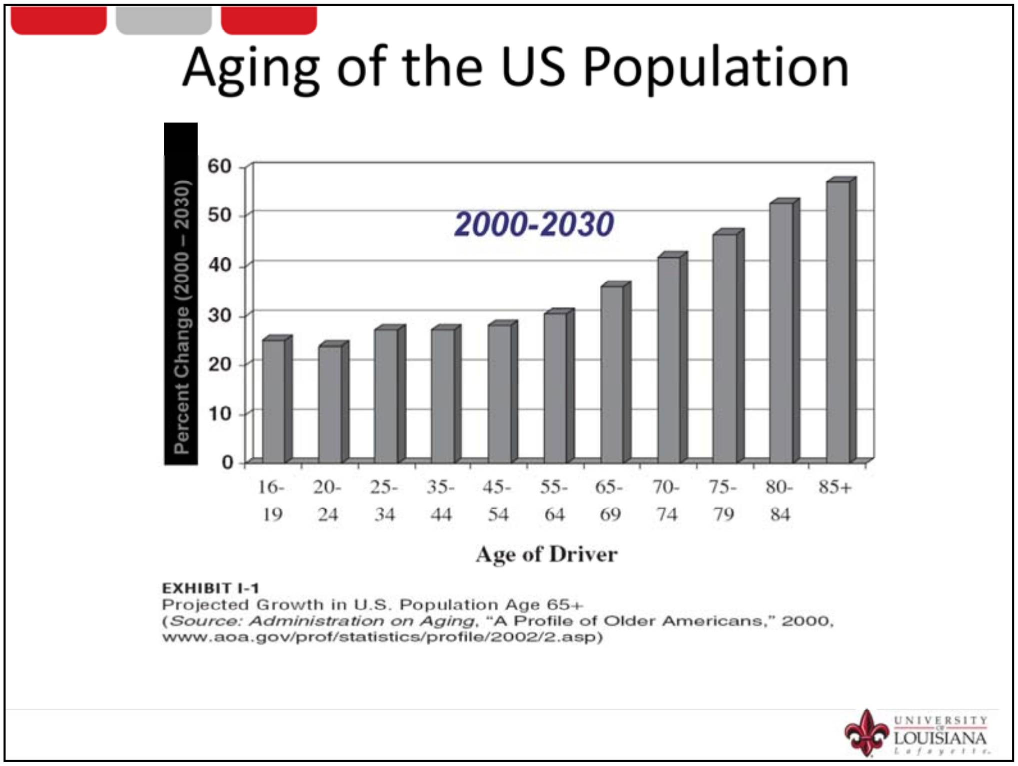
Younger drivers are more likely to be involved in alcohol-related crashes and avoid wearing safety belts than the general population. In 2006, 25 percent of the young drivers who were killed in crashes had a BAC of 0.08 or higher. For young drivers, alcohol involvement is higher among males than among females. Twenty seven percent of the young male drivers involved in fatal crashes had been drinking at the time of the crash, compared to 15 percent of the young female drivers involved in fatal crashes.



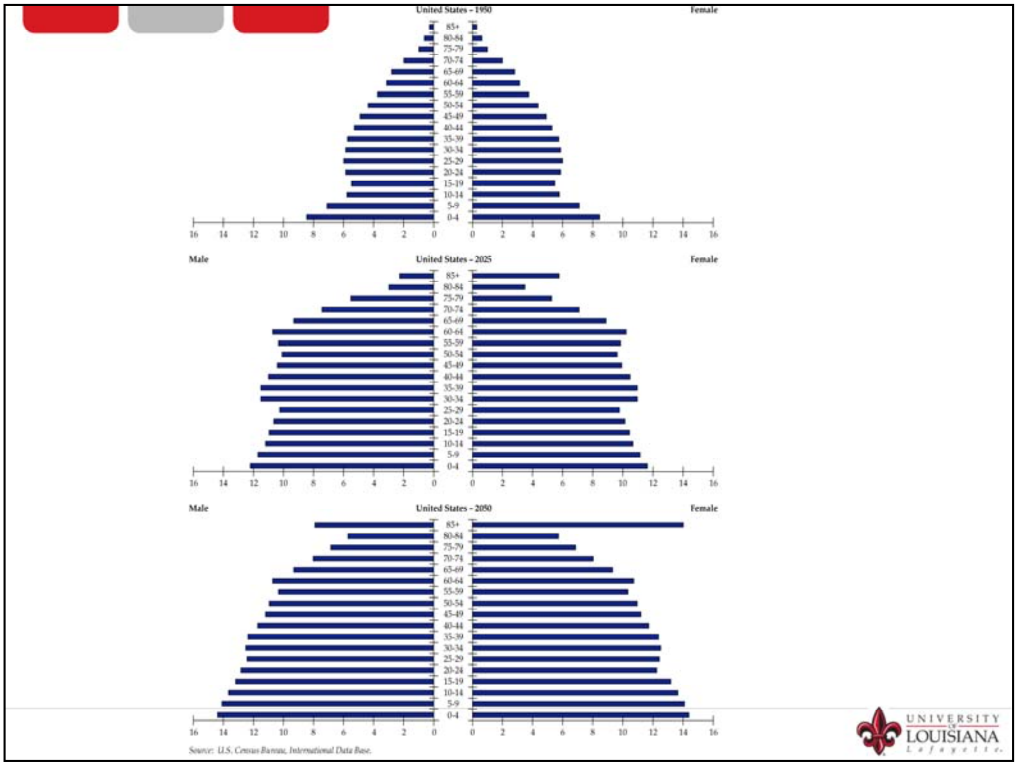
Age-related decreases in vision, cognitive functions, and physical impairments may affect some older adults' driving ability. In 2006, 12 percent of the total U.S. resident population (37 million) was people age 65 and older; yet, they made up 14 percent of all traffic fatalities, 14 percent of vehicle occupant fatalities, and 19 percent of all pedestrian fatalities.

Older drivers do not have quick perception and reaction times compared to their younger counterparts, but they drive less on average than other age groups and avoid driving under perceived dangerous circumstances (e.g., at night, in unfamiliar environments, on high speed roadways, etc.); thus are involved in fewer crashes on a per licensed driver basis. Older drivers tend to drive slower and less aggressively. They are also more likely than the general population to wear safety belts and less likely to drive impaired.

However, older persons are generally the most physically vulnerable to injury in motor vehicle crashes. In general, visual and cognitive performances on driving-related tasks diminish with age. Compared with crashes of younger drivers, older drivers are overrepresented in crashes that involve multi-vehicle collisions and underrepresented in single-vehicle crashes. Older drivers are also more likely to be the responsible party in their collisions.

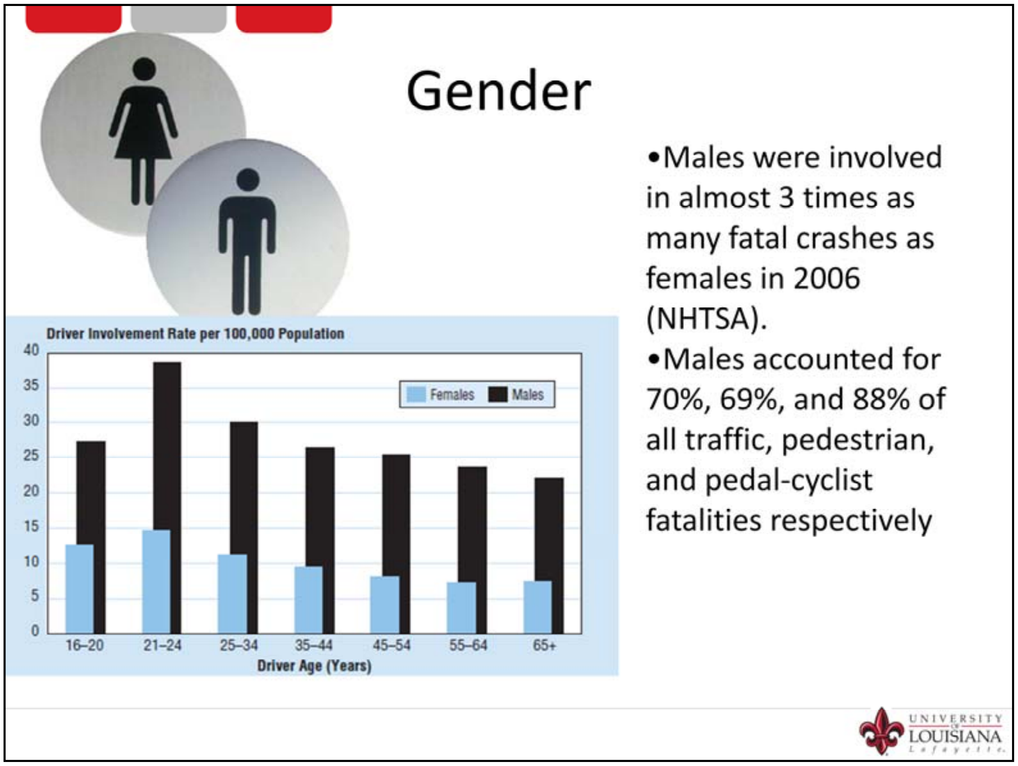


- Potential aging problem in roadway safety



This graphic shows the “squaring” of the population pyramid in the U.S. Where the older population once made up a small percentage of the population, the pyramid is turning into a square. It also shows by 2050, women will be a far more significant proportion of the population compared to previous generations. This presents additional issues in terms of not only safety but also mobility as older women are far more likely to be living alone and in poverty than comparable men. In addition, older women are more likely to self-regulate and take themselves out of the driving environment for reasons which are not entirely clear. More research is needed to explore this issue.

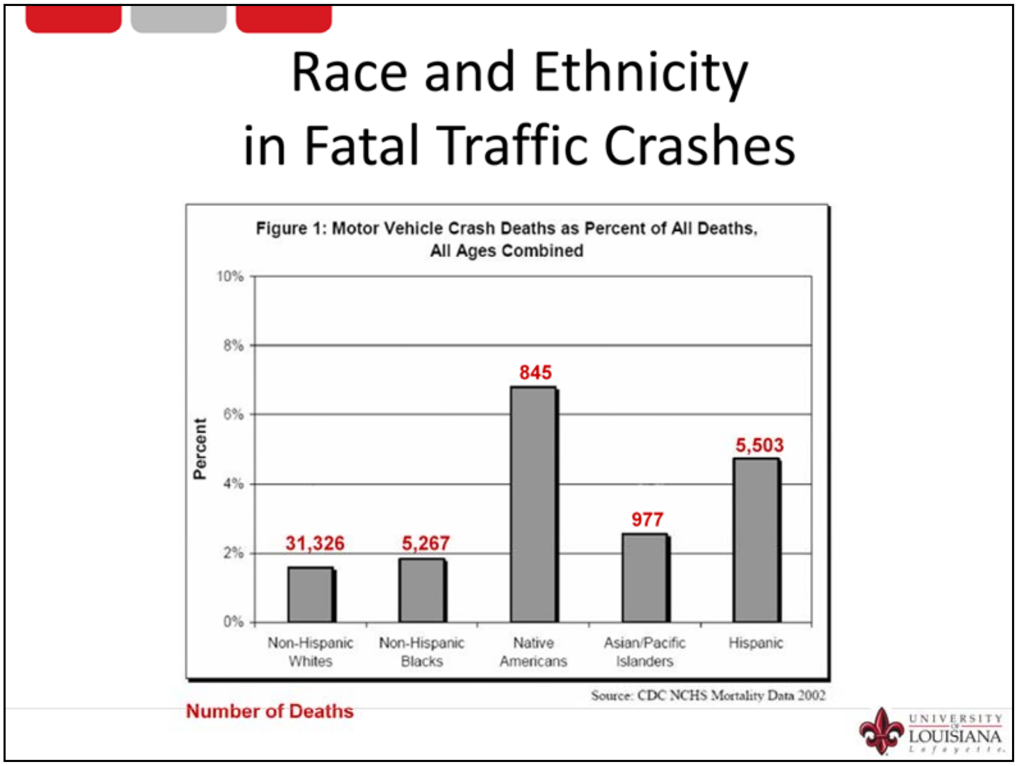
Ref 1: http://www.censusscope.org/us/chart_age.html



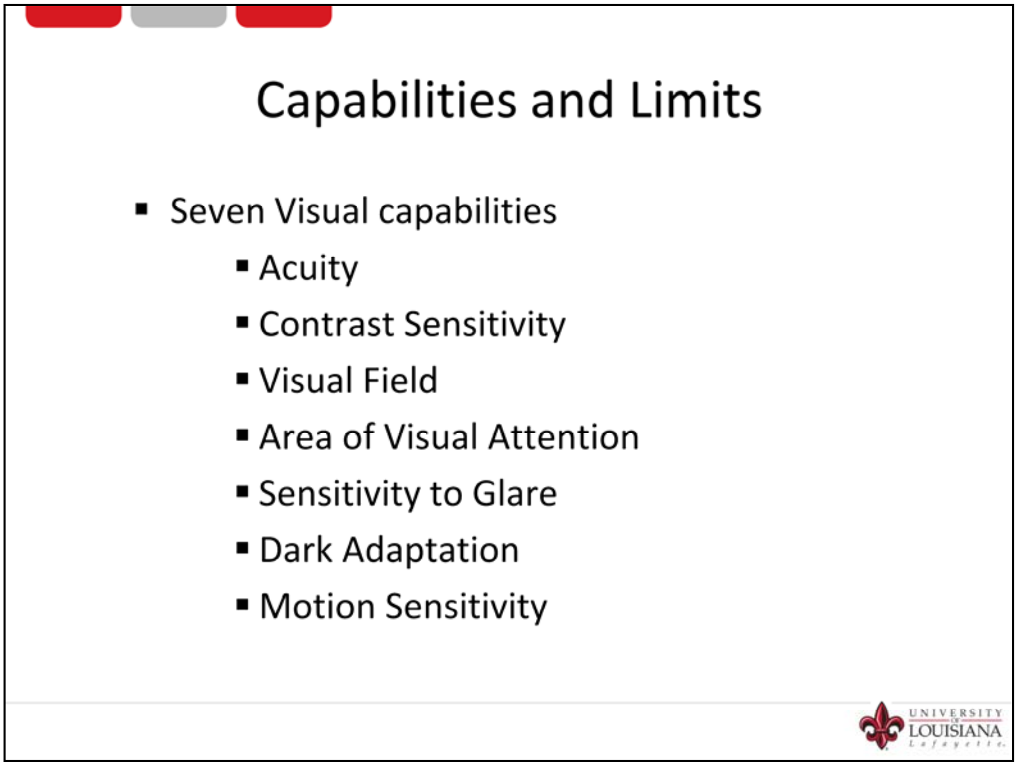
- No gender discrimination, just gender difference in roadway safety!

Ask the participants if they think racial disparity exists on any of the factors listed. According to a technical report published by the National Center for Statistics and Analysis, racial and ethnic minorities are disproportionately killed in traffic crashes, compared with the much larger non-Hispanic White population. The percentage of fatally injured drivers who were drinking was highest for Native Americans (57%) and Hispanics or Latinos (47%).

Fatally injured Native American and Hispanic drivers were less likely to hold valid licenses than White, Asian and Pacific Islander or African American drivers. Native Americans were also more likely to have had prior driving while intoxicated (DWI) convictions and license suspensions. African Americans were the most likely to have had speeding convictions and convictions for other moving violations.



Like gender and age, cultural backgrounds may influence the likelihood of an individual being injured or killed in a crash. Examining how culture influences road safety is essential not only for understanding the causes of safety problems, but also for designing culturally sensitive solutions.



Now let's briefly look at users' physical and mental capacity and limitations. Since 95% information are visual while on roadway, let's first human visual capabilities.

1. One of the visual capabilities which is diminished in older drivers is visual acuity.
2. Definition of VISUAL ACUITY is:
   - The ability to pick out fine detail and high contrast features. It is necessary for reading information on road signs.
3. What is the first test in obtaining a driver's license? (a vision test)
4. Can you obtain a driver's license if you are deaf?
5. Can you obtain a driver's license if you are blind?
6. Experts tell us that more than 80% of the information in the driving task is visual information; being able to see and see *well* is crucial to the driving task.
7. Visual acuity of 20/40 with or without corrective lenses for both eyes or one blind eye is the predominant minimum standard for driver licensing for passenger car drivers. However, there are an increasing number of states (including Pennsylvania, Maryland, New Jersey, Illinois, and others) that will grant low-vision drivers with acuities as poor as 20/70 to 20/100 a restricted license.

View with Normal Contrast Sensitivity

View with Poor Contrast Sensitivity

Source: VISTECH

An example on contrast sensitivity

People require 2 times the amount of light for each 10-13 years after the age of 25

- Visually detect the same information

View at Age 20 | View at Age 60 | View at Age 70

Based on HIGHWAY DESIGN HANDBOOK FOR OLDER DRIVERS AND PEDESTRIANS

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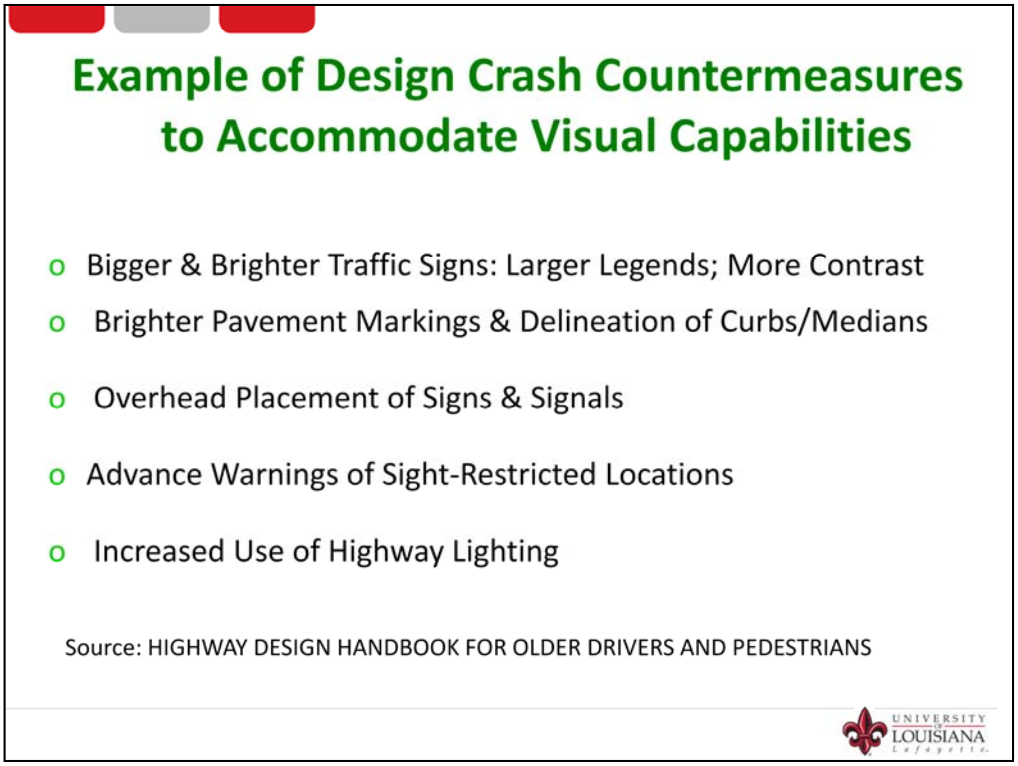
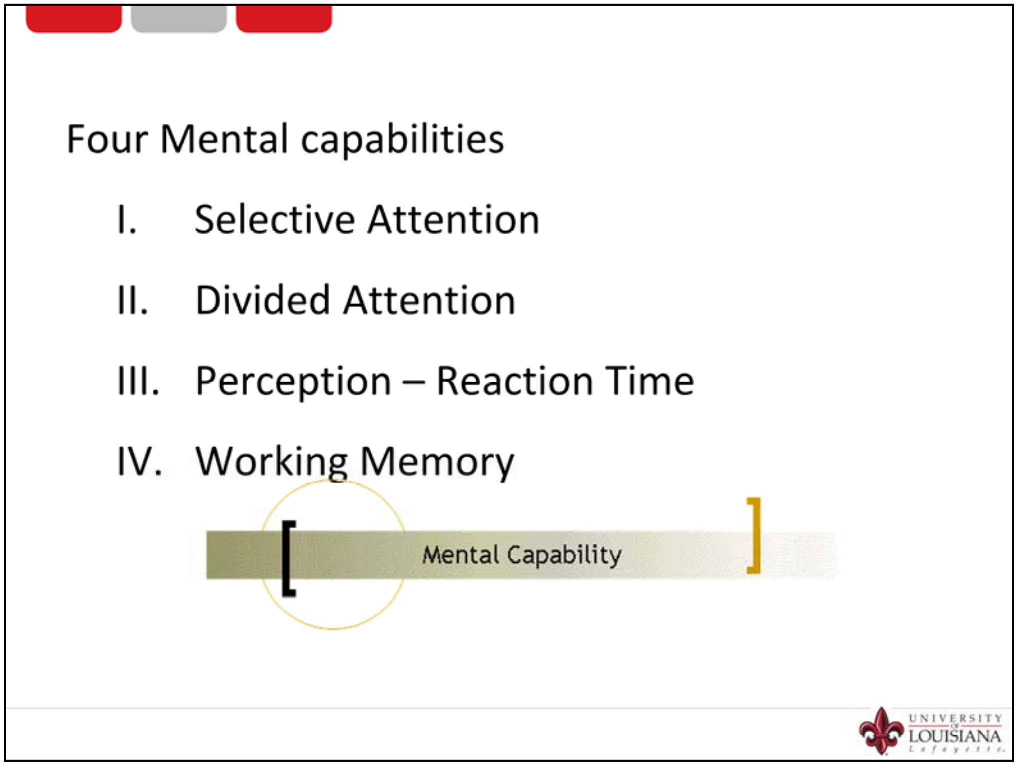
Another sad example--we will all get old sooner or later.

- Diminished Visual Capabilities & Consequences for Driving Performance



Few examples: something we can do collectively to make roadway travel environment safer for people at all ages.



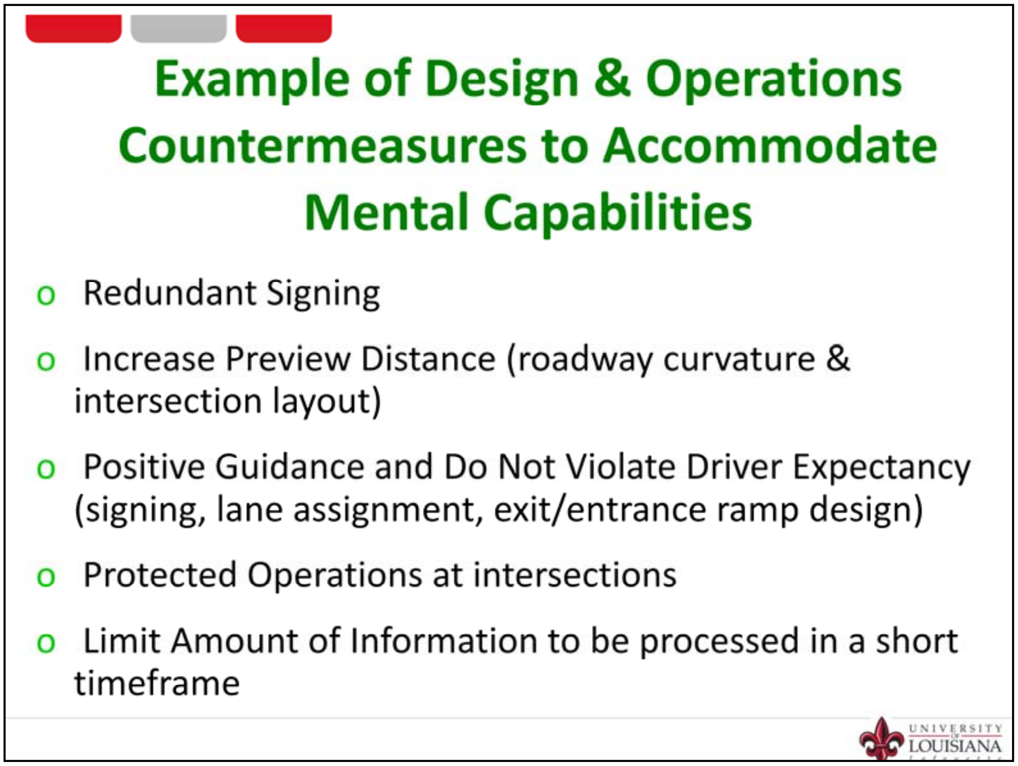
Brief mental capability discussion:

- ability to filter information and continuously focus on the most critical information
- ability to process information from multiple sources simultaneously
- time to make a decision and then physically respond with a controlled vehicle movement
- ability to store, manipulate, and retrieve information for later use

This slide represents the area that we are able to take in at a glance and process appropriately. Our "attention window" or "useful field of view" is not merely what we can see, but what we are able to process visually. The following three pictures may help show you what happens to your attention window as a result of distraction or age-related slowing of information processing.

In this first picture, you see a large attention window (white, unshaved area), which is common among individuals with no visual information processing restrictions. When people have a normal sized attention window, they can make timely responses even to unexpected events occurring away from the forward focus of attention.

In this next picture, the smaller white area shows an attention window that has shrunk; when this happens, people can't process information as efficiently and are extremely sensitive to distractions. People with a smaller attention window are often surprised by turning cars, pedestrians, etc. In this next picture, the smaller white area shows an attention window that has shrunk; when this happens, people can't process information as efficiently and are extremely sensitive to distractions. People with a smaller attention window are often surprised by turning cars, pedestrians, etc.



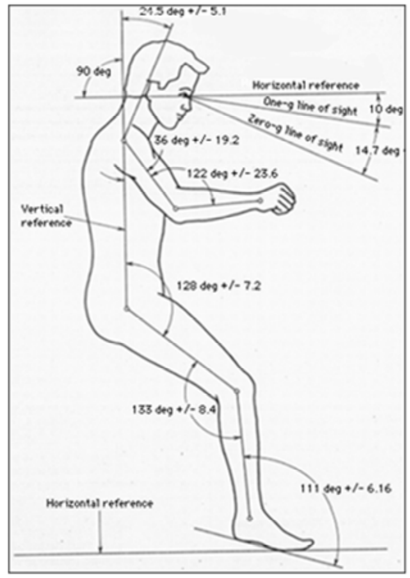
Again, few examples on what we can do collectively to make roadway travel environment safer for people at all ages.

Three_Physical capabilities

I. Upper Arm & Shoulder Strength, Flexibility, and Range of Motion

II. Lower Leg Strength, Flexibility, and Range of Motion

III. Head/Neck and Upper Torso Flexibility and Range of Motion



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- Aging (as well as disease and disuse) brings about changes in the components and structure of the bones, ligaments, joints, and muscles. These changes may impair a driver's ability to control their vehicle in a timely fashion.
    - 14% of men and 17% of women over age 65 experience reduced arm and shoulder flexibility (upper limb impairment). Strength & range of motion in the arms are related to the ability to turn the steering wheel to negotiate turns at intersections.
- Research has shown that: (1) Women age 65+ who have difficulty in extending their arms above their shoulders are at a 2-fold elevated crash risk compared to those without this difficulty; and (2) Older persons with bursitis that caused pain and limitation of shoulder mobility had a crash rate of twice that for people without bursitis of the shoulder. About 30% of men and 43% of women over age 65 experience reduced leg, knee, ankle, and foot flexibility (lower limb impairment). Strength and range of motion of the legs determine the ability to move the foot from the accelerator to the brake.
- Perhaps most common is the age-related decline in head and neck mobility. Joint flexibility has been estimated to decline by approximately 25 percent in older adults, due to arthritis, calcification of cartilage, and joint deterioration. This restricted range of motion reduces an older driver's ability to effectively scan to the rear and sides of his/her vehicle to observe blind spots, and can also hinder the timely recognition of conflicts during turning and merging maneuvers at intersections.
- Drivers with a limited range of motion in their neck were 6 times more likely to have been in a crash, cited for a moving violation, or stopped by police in the year after health assessment compared to older drivers without impairments in neck flexibility. Difficulties in scanning could result in unsafe maneuvering when there is a need to:

Look over your shoulder before changing lanes.

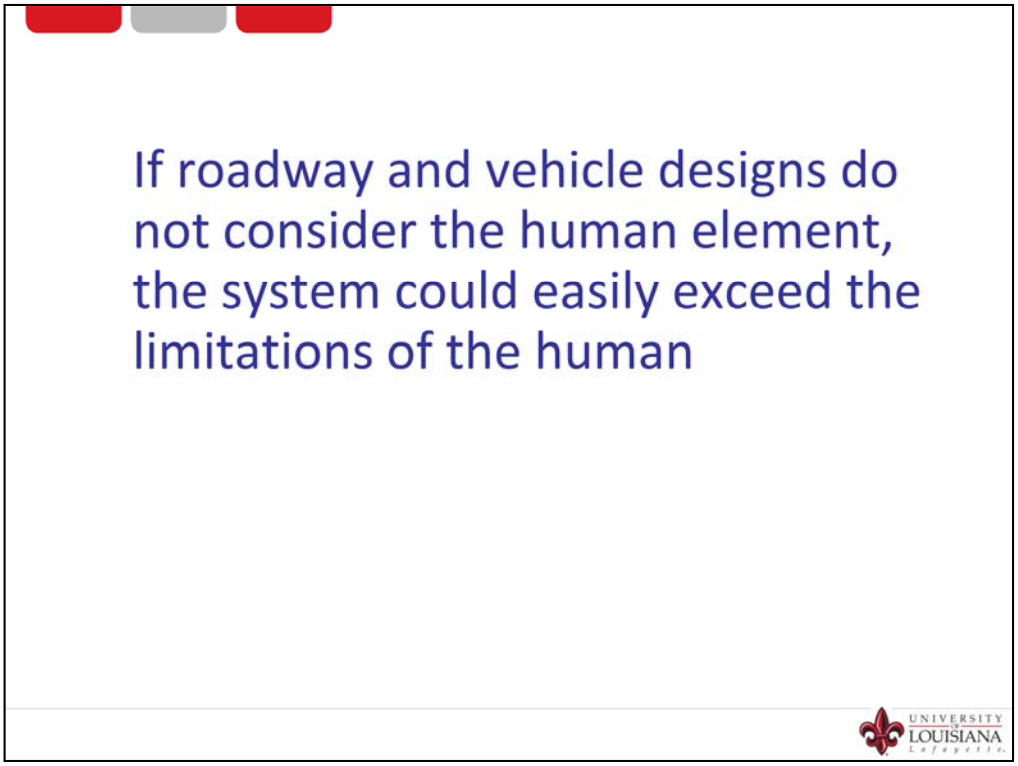
Look behind you as you approach the mainline of a freeway from an entrance ramp.

Look behind you before entering a through lane from an acceleration lane, after making a right turn at an intersection.

Look for cross traffic at a skewed intersection before proceeding.

More examples

- Eliminate skewed junctions (strive for 90 degrees, but no less than 75 degrees).
- Maintain minimum 3.7 m (12 ft.) lane width, particularly for receiving lanes at intersections and on arterials with horizontal curvature.
- Increase perception-reaction time (PRT) value from 2.0 seconds to 2.5 seconds for calculation of intersection sight distance (ISD) for ISD Cases I-V, where unrestricted sight distance is not feasible.
- Design intersection corner curb radii at a minimum of 7.5 to 9 m (30 ft.).
- Use parallel rather than tapered entrance ramp design for freeway merging operations.
- Design longer acceleration lanes and merging/weaving areas.
- Base pedestrian control signal timing on an assumed walking speed of 0.85 meters/second (2.8 feet/second), rather than the 1.2 meters/second (4 feet/second) value, as recommended in the MUTCD.



Human factors and biomechanics professionals study the capabilities and limitations of the human body, often in relation to the design of various devices and systems. Within the transportation field, the human factors and biomechanical elements are critical to the safe design of the vehicle as well as the safe design and operations of the roadway. Biomechanics help explain the physical durability and limitations of the human body.

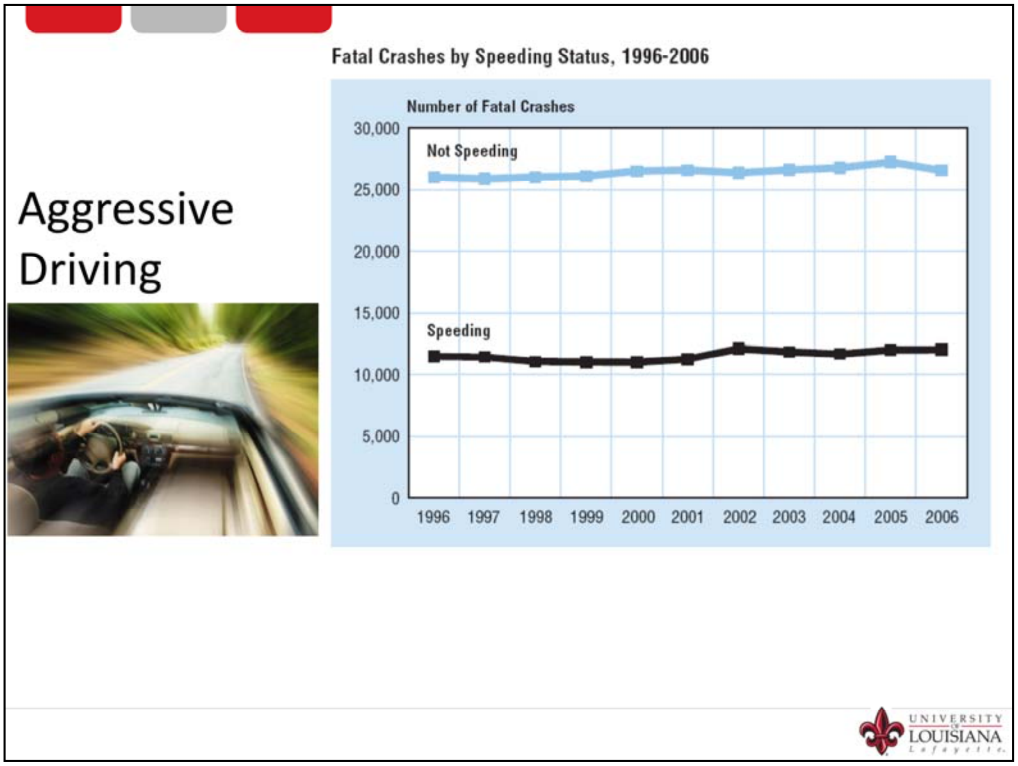
Changeable Behavior?

- Behavioral Factors
  - Aggressive driving
  - Impaired driving
  - Occupant protection
  - Illegal Driving
  - Driver Inattention

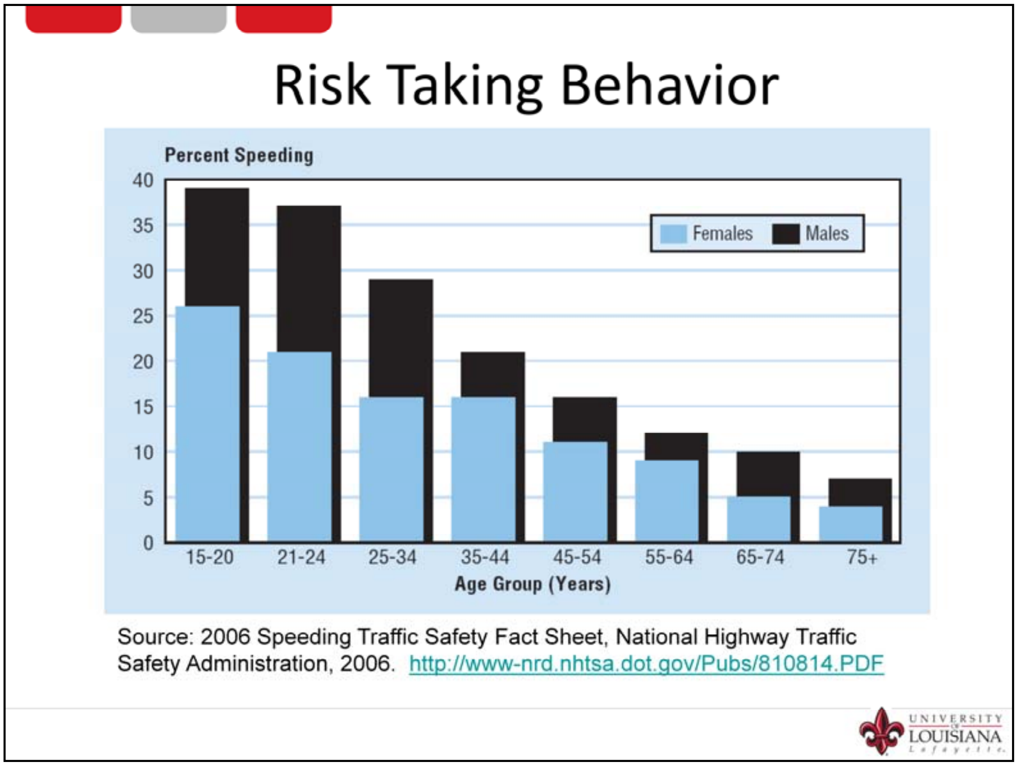
Now comes the most critical user element: (Chinese slogan) “You can change mountains and rivers but not a person's nature.”

But we must!

Such crashes are happening everyday!



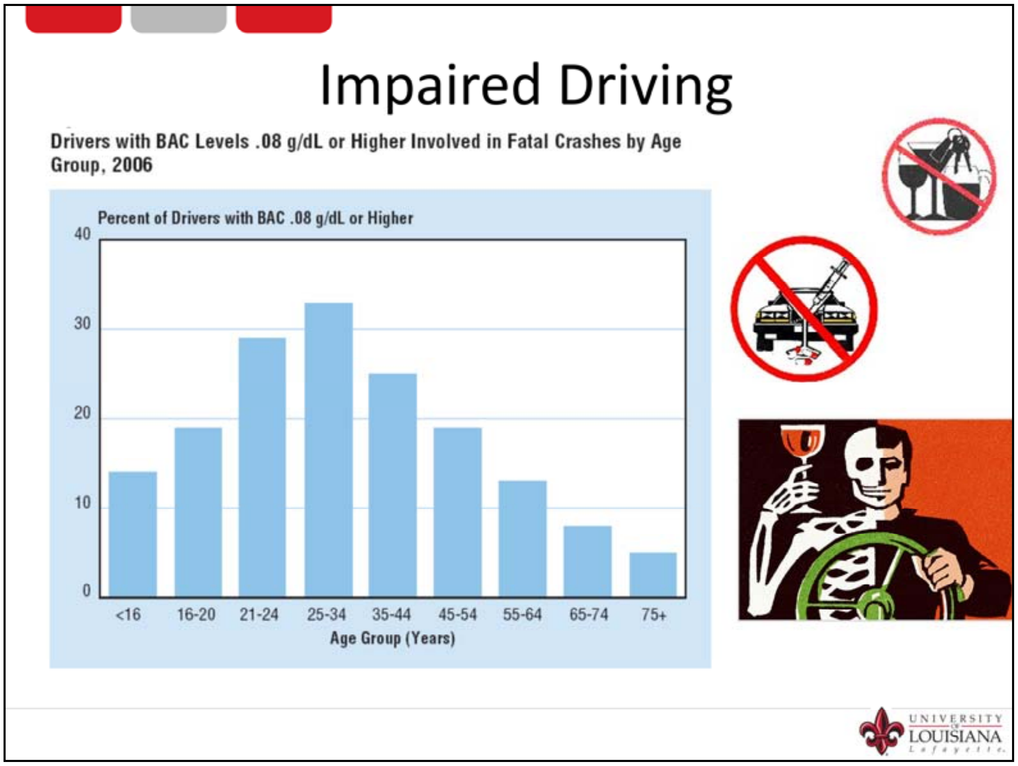
Manifestations of aggressive driving include driving too fast for conditions (unsafe speeding), following too close for conditions, passing in unsafe conditions, etc. A common thread in aggressive driving is the choice to drive too aggressively considering the prevailing conditions. According to NHTSA, speeding was a contributing factor in 31% of all 2006 fatal crashes, resulting in 13,543 lives lost. The number of fatal crashes involving speeding is shown in the table. Speeding is a difficult concept to nail down because definitions vary widely. However, when you think about it, if drivers are paying attention and not speeding, they are highly unlikely to be involved in a crash because they will recognize a hazard and correct for it in most cases. In at least one state, the law enforcement training academies (with the exception of the State Police Academy) discourage new recruits from citing speeding as a factor in crash investigations because it is difficult to prove in court.



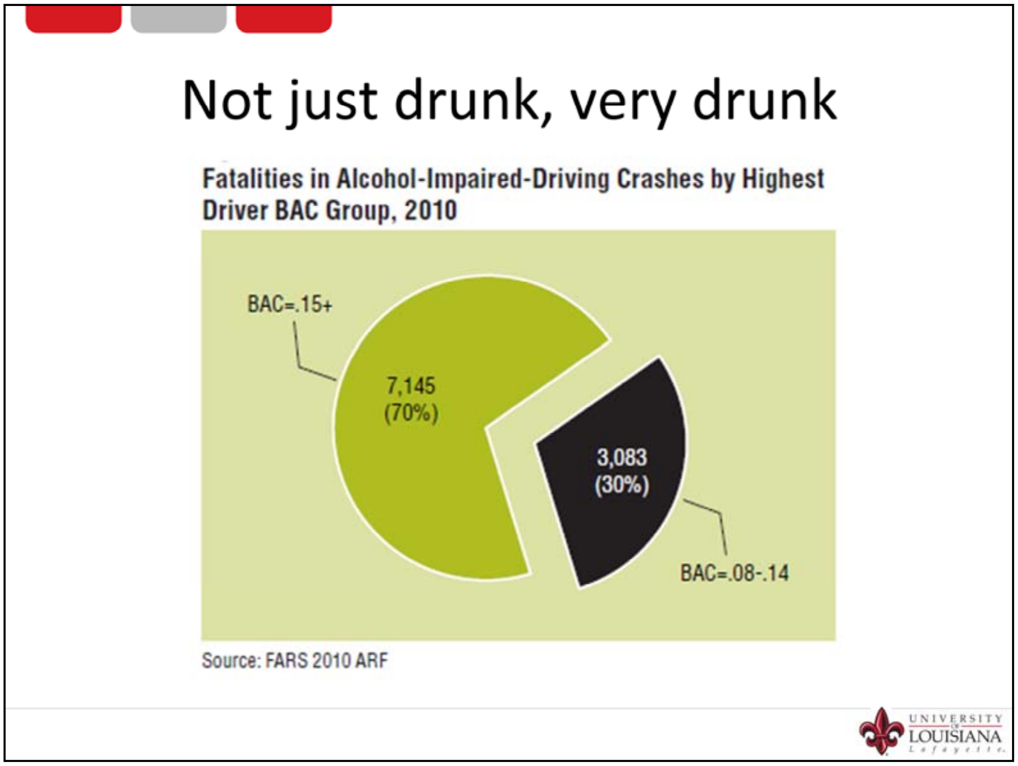
The propensity of an individual to take risks on the roadway is associated with demographic factors such as age and gender. Young drivers, and young men in particular, are much more likely to be involved in fatal crashes not only because of lack of experience, but also because of increased willingness to engage in risky behaviors such as drinking and driving, not wearing a safety belt, and speeding. For example, in 2004, the motor vehicle death rate for male drivers and passengers aged 16 to 19 was more than one and a half times that of their female counterparts (19.4 per 100,000 compared with 11.1 per 100,000). Recently, young women drivers have shown increases in crash involvement, but this phenomenon is not well understood and may be related to greater exposure.

This chart shows the percentage of drivers who were speeding in fatal crashes by age and gender in 2006. It is clear from the chart that the younger a driver is, the more likely they are to be speeding when involved in a fatal crash. It is also clear that men have much higher rates of speeding than women. Older drivers, by contrast, do not engage as much in risky behaviors such as speeding and drinking and driving. In 2006, for example, drivers aged 65 and older had the lowest rates of intoxication among fatally injured drivers. However, it is wise to keep in mind that definitions of “speeding” differ among and within states, so it is important to know exactly what we are examining. Various definitions exist, such as, exceeding the posted speed limit, speeding too fast for conditions, etc.

As a result of in engaging these risky behaviors, a disproportionate number of young drivers die in car crashes. In fact, the risk of motor vehicle crashes is higher among 16- to 19-year-olds than any other age group. Per mile driven, teen drivers ages 16 to 19 are four times more likely than older drivers to crash.



Driving while intoxicated, under the influence of drugs (illegal, over the counter, or prescription), or fatigued all are known to contribute to crashes. According to NHTSA(1), there were 17,602 alcohol-related fatalities in 2006, 41% of all traffic fatalities that year. These data too may be underreported. For example, it is far less likely that a 65 year old women who experiences an intersection related fatal crash will be tested for impairment than a 21 year old male who crashes at 2:00 AM. It would be ideal if all states tested all persons involved in fatal crashes; however, as noted throughout the course, law enforcement officers have their hands full at the scene of a crash and often contributing crash factors are overlooked.


Not just drunk, very drunk
Fatalities in Alcohol-Impaired-Driving Crashes by Highest Driver BAC Group, 2010
BAC=.15+
7,145 (70%)
3,083 (30%)
BAC=.08-.14
Source: FARS 2010 ARF
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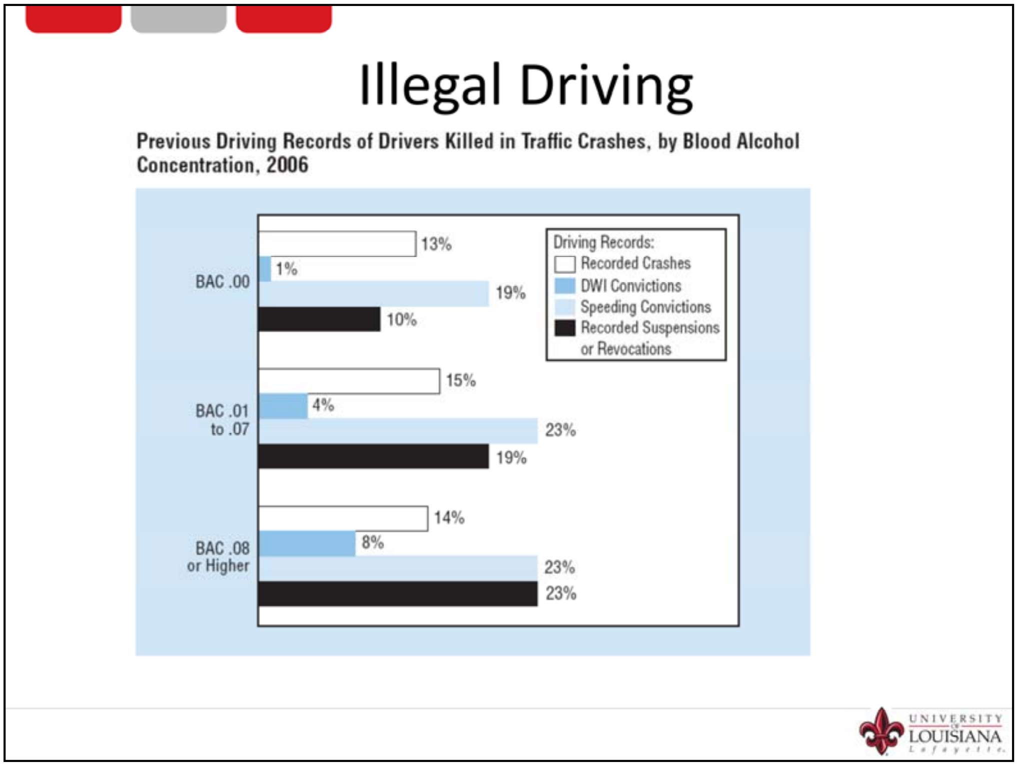
A sad fact!



Driving with a revoked license, without a license, and without insurance tends to be associated with high-risk driving. NHTSA has developed statistics showing the relationship among of prior convictions, speeding convictions, recorded suspensions and drivers BAC levels in fatal crashes in 2006.

Over 84% of driver fatalities involve one of these three factors of the driver killed.

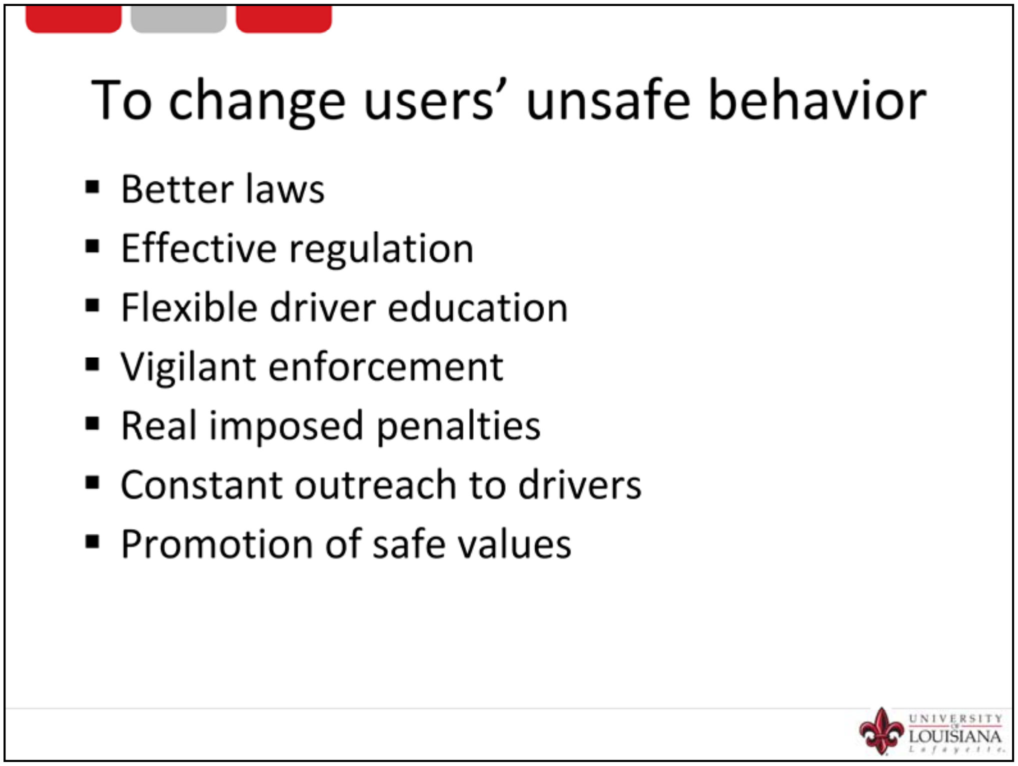
62%

48%

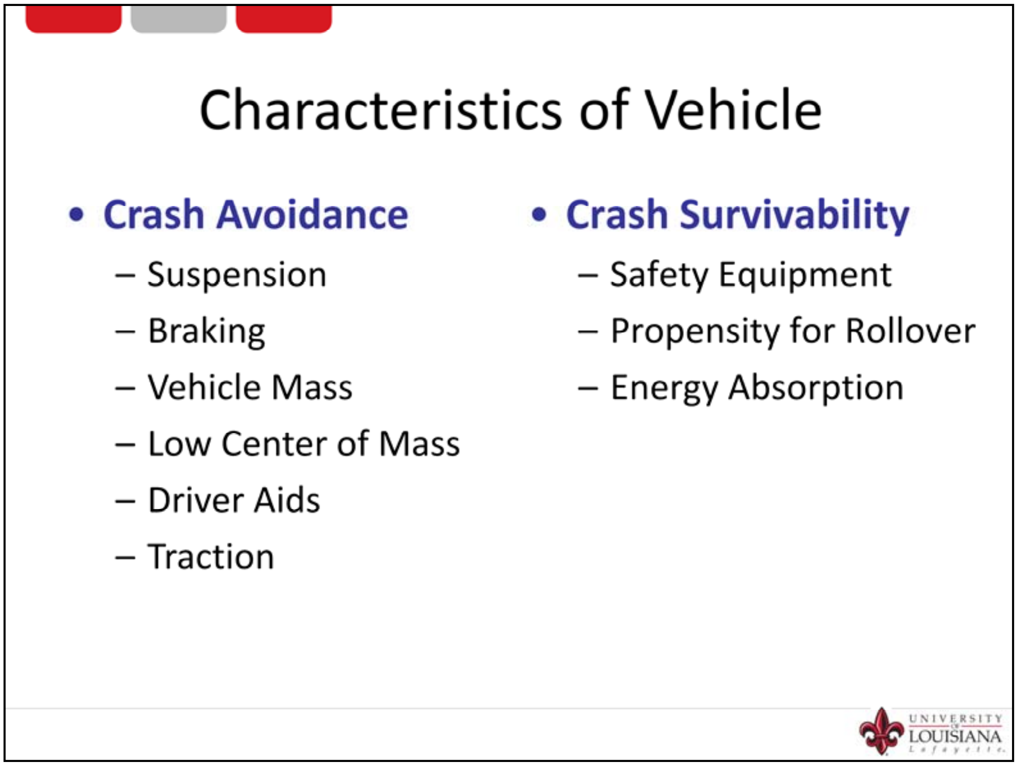
51%

"This is accepted as Louisiana's Culture –
We need to change this culture!"
-- from the 2009 LaDOTD Safety Summit

Can we change the culture and how?



Each of these can be done, which has been proved in other countries.



Now on another system component.

Vehicle design is a significant factor for road safety. The tradeoffs between large and small vehicles are complex and poorly understood due to very different relationships with crash risk, and because we typically only observe crashes after they happen (and not crashes that are avoided). In general, newer vehicles have better safety equipment and performance characteristics than older vehicles.

We can classify vehicle safety factors into two categories:

- Crash avoidance Factors that help to prevent a crash. Numerous factors are incorporated into vehicles that help prevent crashes. In general, the more maneuverable and agile a vehicle is the more likely it is that it can avoid a crash. Also light, compact, and low vehicles offer superior maneuverability compared to heavy, large, and tall vehicles. Major factors that contribute to good maneuverability are:
- Crash survivability: Once a crash occurs, a different set of vehicle factors become important. The survivability of a crash depends on many factors. The following factors do not affect how many crashes occur, but how severe they are.
- Safety equipment: airbags, safety belts and child car seats, crumple zones, energy absorbing designs, forgiving interiors, etc.
- Propensity for rollover. Vehicles that rollover typically result in greater injuries than those that do not. Rollover probability is related to center of mass as well as other vehicle dimensions and attributes.
- Energy absorption. The key to crash survivability is the ability of the vehicle to absorb energy over a long period of time (scale of milliseconds). All else being equal, more massive vehicles have more energy absorbing potential than less massive vehicles.

New Auto Technology Can Tell When You're 'Driving While Drowsy

- In the age of multilingual GPS devices, driver seat massages and cruise control navigation, it was only a matter of time before manufacturers developed drowsy driver alerts.
- Useful additions to driver safety is emerging in various forms and functions.

Crash Avoidance: Driver Aids

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An example on safe vehicle:

That's right – technology to tell you when you're in danger in nodding off behind the wheel, bringing you back to full attention through dashboard icons and warning alarms.

- In fact, it's all rather rational. The fatigue detection systems, shown here on the vehicle's dashboard, monitors eyelid closure. The device emits a beep alerting a driver who has closed her eyes longer than a threshold amount of time that she should take actions to maintain alertness.

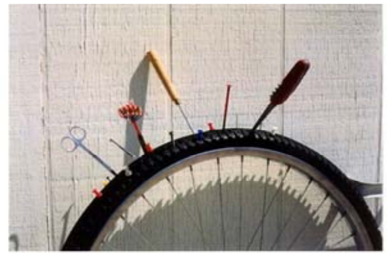
One person's lack of sleep can contribute to another's lack of safety on the Nation's roads. According to the National Highway Traffic Safety Administration's (NHTSA) Senior Research Psychologist Jesse Blatt, fatigue and sleep deprivation contribute to about 100,000 police-reported highway crashes, causing more than 1,500 deaths annually in the United States.

- All this technology is aimed at reducing the number of crashes caused by drowsy drivers, which the National Sleep Foundation estimates at 100,000 per year.
- 20% of all traffic crashed caused by drowsy drivers

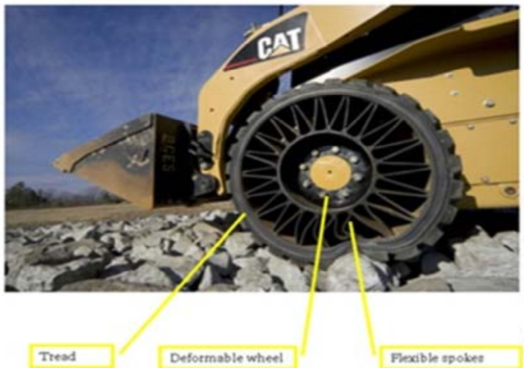
And then there are $250 dashboard devices, like the Danish-made Anti-Sleep Pilot set for U.S. release in the coming months which uses sensors charting 26 different factors to detect tiredness. Drivers using that product also have to tap the sensor every 10 to 15 minutes, with reaction times measured.

Much safer vehicles

- Seat Belts
- Anti-lock brakes
- Puncture-resistant tires
- Air bag
- Crumple zone (absorb kinetic energy)



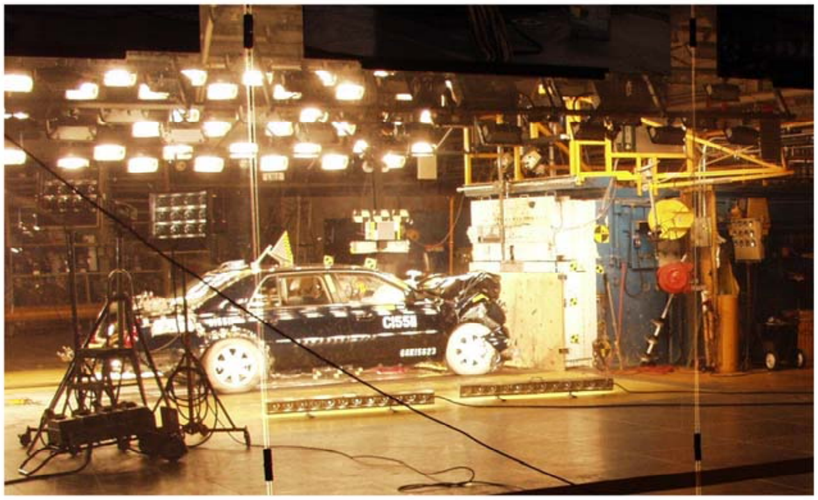
No more flat tires



Claimed benefits of Michelin TWEEL :

- maintenance-free
- easy mounting and dismounting
- puncture-proof
- longer wear resistance
- better distribution of pavement stress
- simplified manufacturing process
- reusable base structure for retreading
- improved shock and road hazard resistance

Vehicle crumple zone design



General Motors Vehicle Safety and crash Worthiness Laboratory

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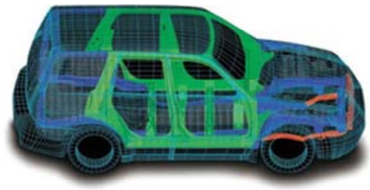
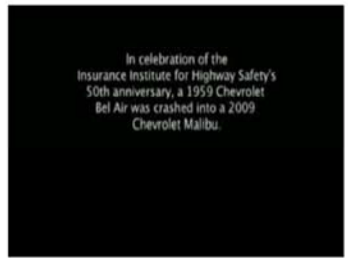
Vehicles of the 50s, 60s and 70s were literal death traps compared to today's cars.





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Two crash tests to show the significant improvement on vehicle design.

To get to this day, there are many legal issues needing to be resolved.
It will certainly solve many safety problems.

Which type of vehicle is safer?

- Passenger Cars
- Commercial Vehicles
- Motorcycles
- Commercial Vehicles

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Back to today's reality, we know which type of vehicle is safer.

The most popular mode of transportation is the passenger vehicle (e.g., cars, SUVs, vans, and light trucks) when considering total miles traveled. As such, the design of transportation facilities has reflected the desired use of the automobile. However, the passenger car is also represented in the largest percentage of crashes. In 2005, more than 94 percent of the 11 million vehicles involved in motor vehicle crashes were passenger cars (NHTSA, 2006). But…

Comparison of Vehicle Type Involved in Crashes

Vehicle Type	Crash Type	Total Number of Crashes	Rate (per 100 million vehicle-miles traveled)	Rate (per 100 million registered vehicles)
Passenger Cars	Fatal	25,029	1.55	18.52
	Injury	1,893,000	117	1,401
	Property Damage	4,169,000	258	3,085
Light Trucks	Fatal	22,838	2.01	24.05
	Injury	1,209,000	107	1,273
	Property Damage	2,919,000	257	3,074
Large Trucks	Fatal	4,932	2.21	58.15
	Injury	82,000	37	971
	Property Damage	354,000	159	4,176
Motorcycles	Fatal	4,655	43.22	74.75
	Injury	80,000	746	1,291
	Property Damage	18,000	168	291

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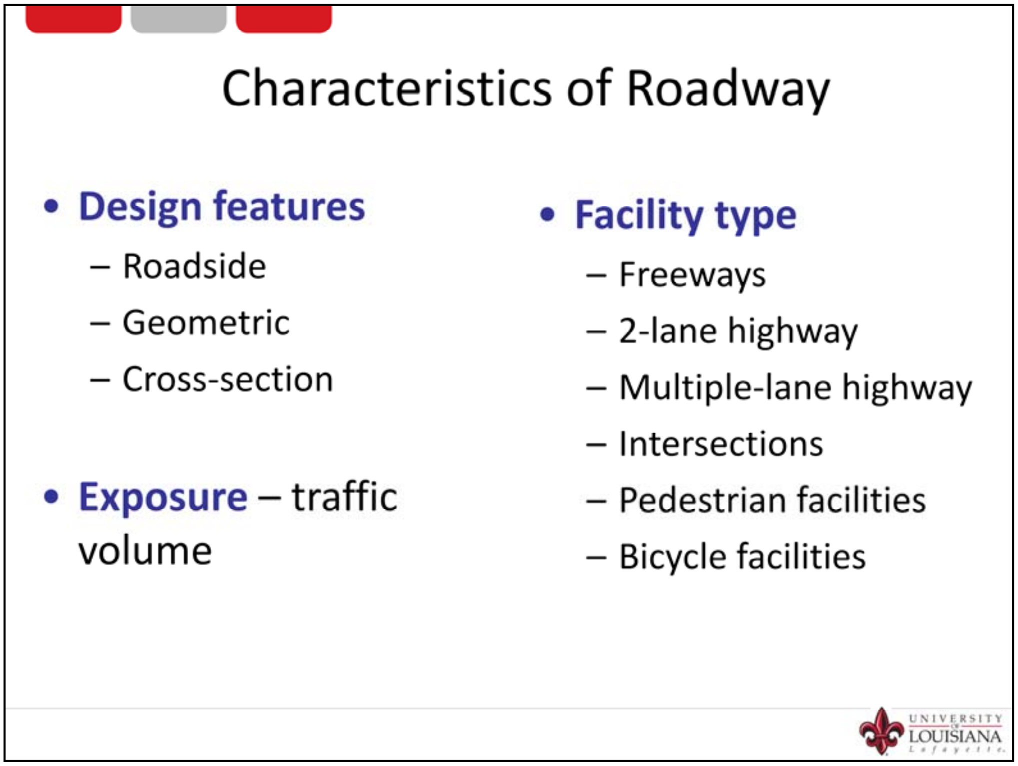
Passenger vehicles are involved in many more fatal and injury crashes than other types of vehicles. However, controlling for vehicle miles of travel and number of registered vehicles, passenger vehicles are the least likely to be involved in serious crashes. Does this mean that passenger vehicles are “safer” than other types of vehicles? Not necessarily. We have to consider who is driving; where they are driving; and break the data down much further to answer this question. For example, the fatal and injury rate for large trucks is higher than passenger vehicles; however, it is generally not the truck occupants who are injured or killed but rather the passenger vehicle occupants.



It is time to talk about roadway infrastructure designed by us—civil engineers!

In addition to human factors and vehicles, roadway factors also influence the likelihood and severity of crashes. In many cases, human and roadway factors interact to contribute to a crash, such as a distracted driver driving through standing water, an aggressive driver hitting an edge rut, etc.

The most important factor contributing to crashes on any road (interstate, intersection, ramp, etc.) is the amount of exposure to risk of the road for a given time period. Exposure is directly related to traffic volumes (vehicles per mile) on road segments and entering volumes at intersections. The number of vehicles a facility is exposed to will be a dominant factor in explaining the crash experience at the location.

Roadway factors are grouped predominately by the types of facilities comprising the transportation system, including (but not limited to) interstates, intersections, rural highways, local roads, pedestrian facilities, and bicycle facilities. Safety of these different facilities varies greatly because they are built to different standards and vastly different types of activities occur on them, and often simply knowing the type of facility will provide an important indicator of safety. For example, intersections are locations of a large amount of conflicting vehicle movements, whereas rural highways are often locations of high speeds and unforgiving roadside environments.

Representative Accident Rates by Location and Type of Road			
	Fatal Accidents	Injury Accidents	Total Accidents
RURAL	Number per MVM	Number per MVM	Number per MVM
2 Lanes	0.07	0.94	2.39
4 or more lanes, divided subtotal	0.063	0.77	2.09
Freeway	0.025	0.27	0.79
URBAN			
2 Lanes	0.045	1.51	4.94
4 or more lanes, undivided	0.04	2.12	6.65
4 or more lanes, divided	0.027	1.65	4.86
Freeway	0.012	0.4	1.43

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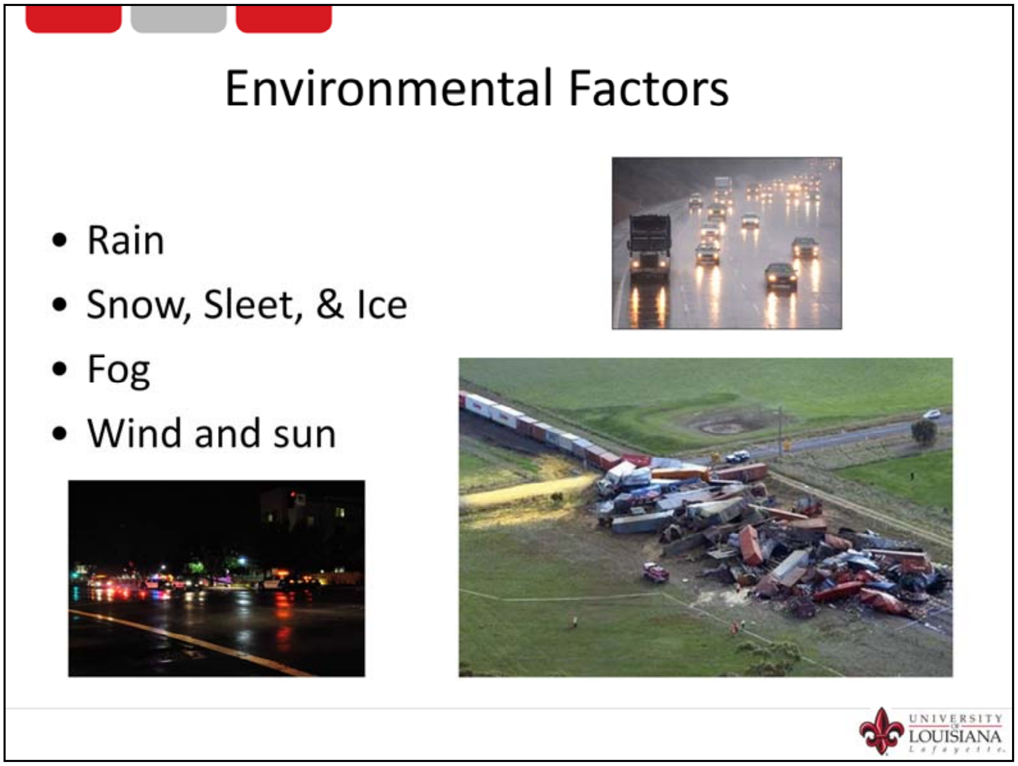
Note that these numbers do not reflect the safety of pedestrian and cyclists. As these travel modes get popular in the future, more attention must be paid to the safety design of pedestrian and bicycle travel facilities, which has been ignored in many states/locations.

Safety for Pedestrians and Cyclists

- Bicycles are legally considered to be vehicles, with the right to use roadways
- There are more than 9 million bike trips and 56 million walking trips in the U. S. everyday
- One in ten U. S. households do not own an automobile
- 1/3 of the population do not drive an automobile
- About 10% of total fatalities are pedestrians each year

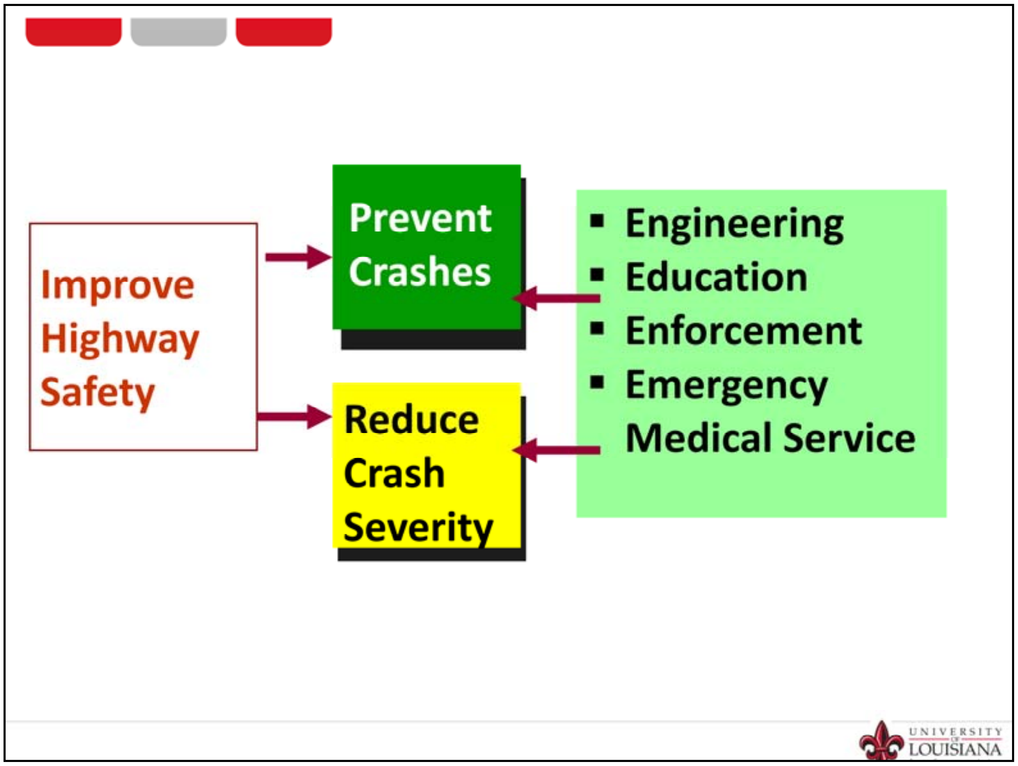
A little discussion on the safety of pedestrians and cyclists. Current urban and suburban street design are not sufficient for safety of pedestrian and cyclists in most states.



Last on environmental factors.

Environmental crash factors are usually related to weather. Environmental factors contribute to crashes typically through interactions with vehicle or driver related factors, but sometimes they are outright responsible for crash occurrences. The following are the most common environmental factors that contribute to crashes.

- Rain. Wet pavement has lower friction than dry pavement, so traction is reduced. Also, pooling of water can lead to hydroplaning and loss of vehicle control. In most wet conditions drivers can accommodate the reduced friction; however, often a crash occurs in wet conditions due to drivers not accommodating sufficiently for the reduced friction between tires and pavement. Finally, rain can reduce visibility.
- Snow, sleet, and ice. Snow and ice (via freezing rain) can be hazardous due to extreme loss of traction.
- Fog. Fog is responsible for a large number of crashes and can lead to massive pile-ups. Fog can reduce visibility for several feet, virtually rendering a driver blind.
- Wind. Windy conditions can also contribute to crashes, especially for large trucks and vehicles.
- Sun. The sun can contribute to crashes because of glare and reduced visibility during periods of high glare.



Now we know to improve safety, we must have the 4E approach.

Last "E"

- "Golden hour" after an injured crash
- Difference in "Life and Death" and "healthy and permanently handicapped"
- Urban: less than 15 min, Rural: less than 30 min.

Lots of improvements have been on this E.

Summary

- Roadway safety is a serous public health, economical, and liability problem to a society
- Building a “multilayer defense system” is critical to reduce annual 1.3 million fatalities and 60 million injuries caused by crashes in the world.

Recap this lecture by summarizing what has been introduced.

Based on a TRB Report

(TRB Special Report 289)

- Meeting the need for safety professionals is a serious challenge
- Recruiting, educating, and training future highway safety professionals are inadequate.
- It is also necessary to provide education and training for existing professionals to enhance their highway safety background and/or knowledge.

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Safety *education is* critical to reach the hefty goal of ASHHTO.

FOR QUESTIONS CONTACT

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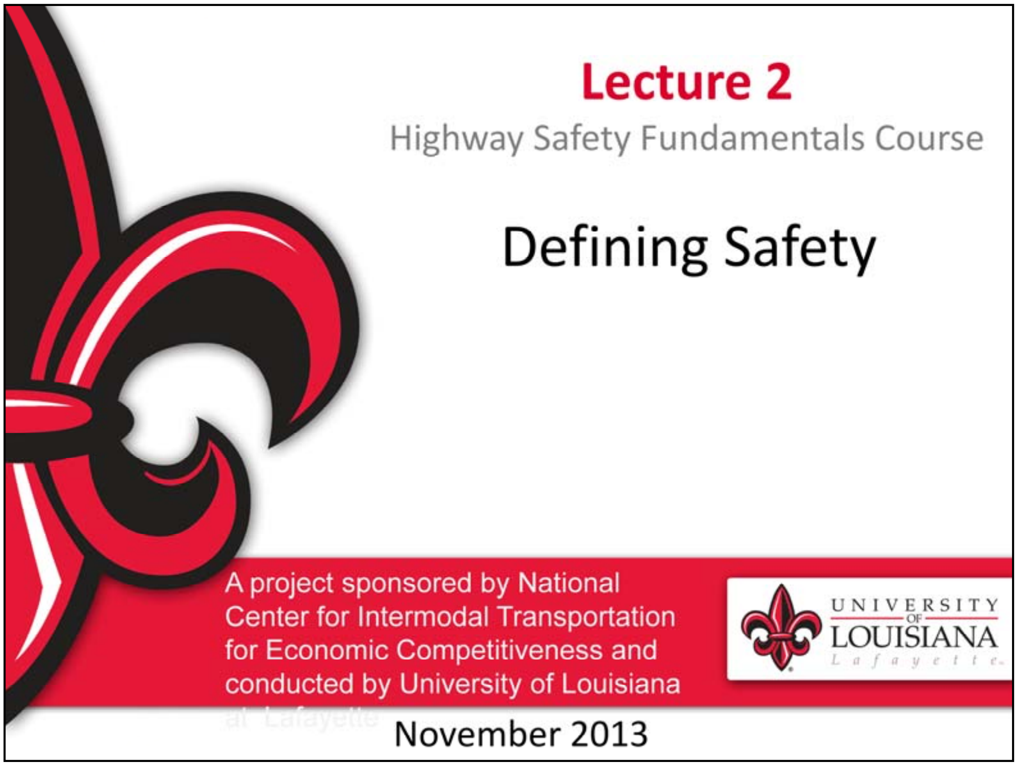
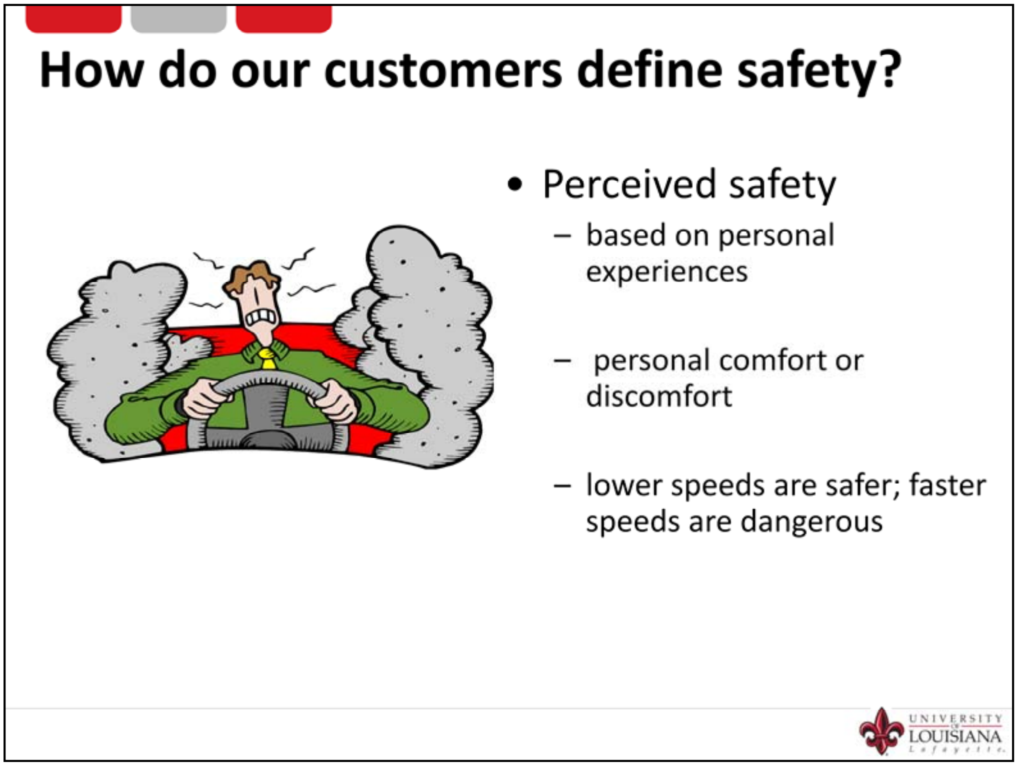


The purpose of this lecture is to let students understand the scientific definition of safety and be familiar with the evolution of basic safety concept. The lecture lays out the foundation for the upcoming analysis methods.

What is Safety?

Start the lecture by asking this seemingly simple question.



Perceptions of what is safe or not safe may not always match actual safety.

It is thought that “lower speeds are safer”; important to know in the urban environment; slower means more time to react, more importantly, more time to perceive events around and process accurately.

How do professionals measure safety?

- Crashes and crash severities
- Crashes per spatial unite
- Crashes per time unit
- Rates (crashes per vehicle-miles-traveled)

Professionals look at the problem from a holistic approach.

Safety in two terms

- Objective Safety (measurable) refers to the number of crashes and their severity.
- Subjective Safety (perceived) refers to the perception of how safe a person is on the road, i.e. the feeling of personal security.

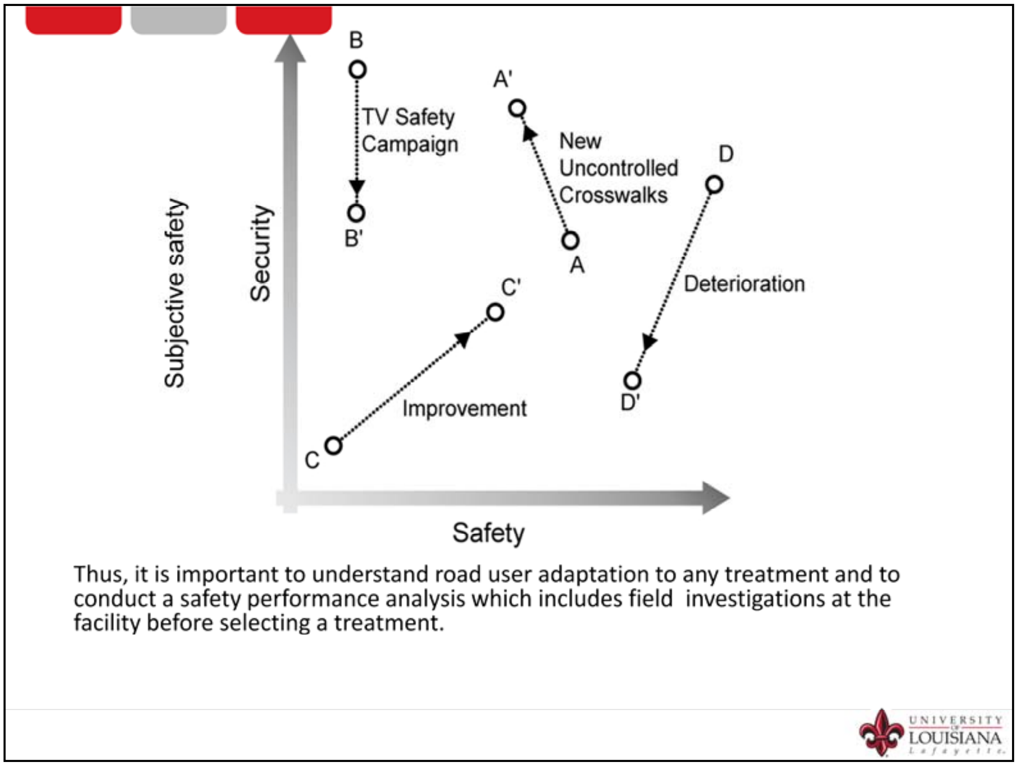
Introduce two important safety definitions.

- Objective safety
  - Quantifiable
  - Independent of observer
- Subjective Safety
  - Perception
  - Values vary between observers

Objective safety and subjective safety do not always go hand in hand.

Must stress the differences between the two.

It is possible that some road treatment or improvement will induce a false sense of security in road users and, as a result, the number of crashes or accident severity increase.



The point marked A indicates the safety of a pedestrian using an uncontrolled midblock crosswalk that is not marked by painted lines, and the pedestrians' feeling of security under such conditions. The point marked A' indicates the safety and security of the pedestrian after the uncontrolled midblock crosswalk edgelines have been painted. Point A' is higher on the vertical axis, indicating that pedestrians have an increased sense of security. However, the safety of this location has decreased with an increase in the frequency of crashes, indicating a false sense of security. Points B and B' indicate the safety and security values before and after a TV-based safety publicity campaign respectively. In this case, road user security decreases while safety may have increased very slightly or not at all. The effects illustrated by A to A' and B to B' are not clear-cut improvements. However, the change between points C and C' indicate a clear-cut improvement in safety as well as security (such as flattening a severe sideslope). The change between points D to D' illustrates a clear-cut deterioration in both safety and security (such as eliminating illumination). Real-life treatments may be of the A, B, C or D types, and their effects on both safety and security are important.

Discuss this seemingly confident pedestrian crossing situation.

Safety is what actually happened in the real world

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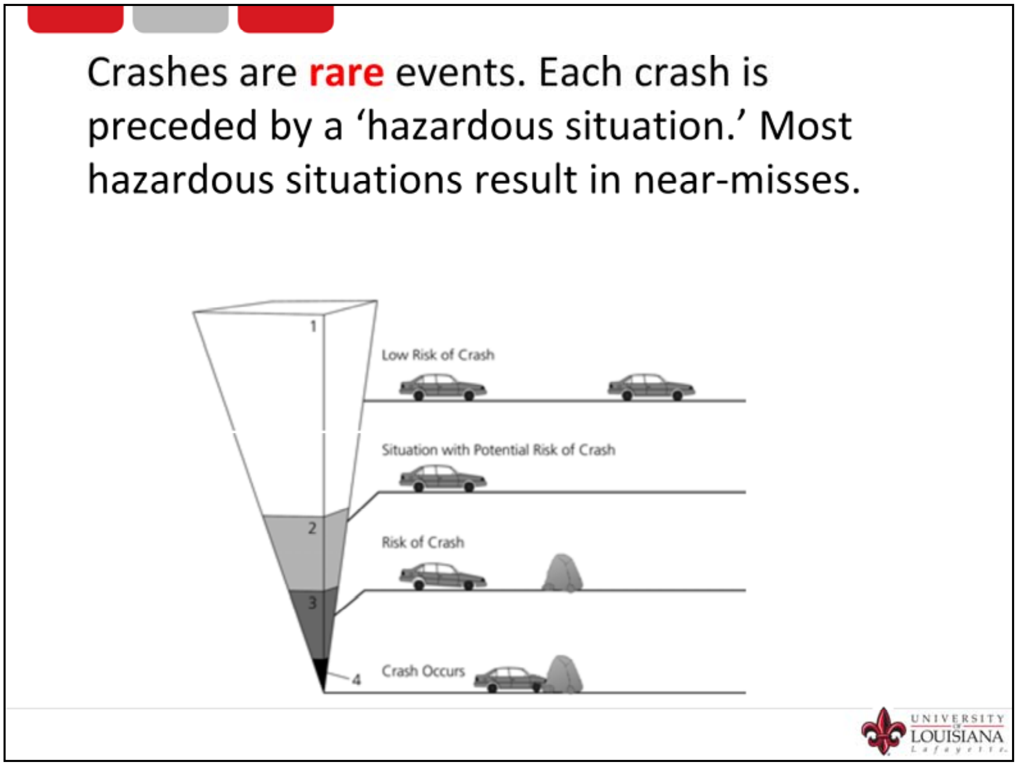
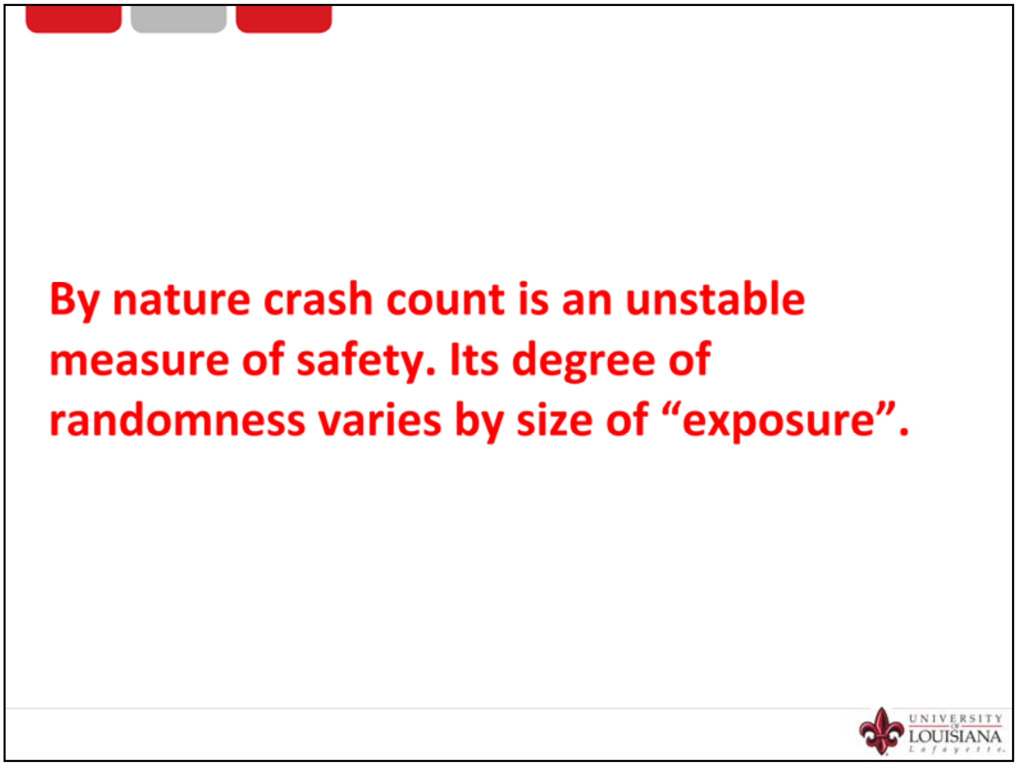
Highway safety is certainly not about personal experience, feelings, or anecdotes.

So, crash counts are related to safety, but it must be know that…..

Number of crashes per unit time and location is a measurement of safety as you may think.



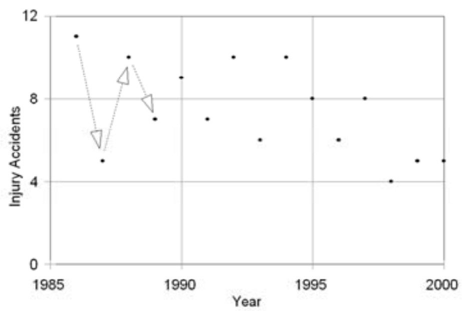
Although crashes are what we want to account for safety at the top, we need to understand how it occurred and their relevance the blocks above. [Safety as a continuum of events (not total independent from other events/situations]



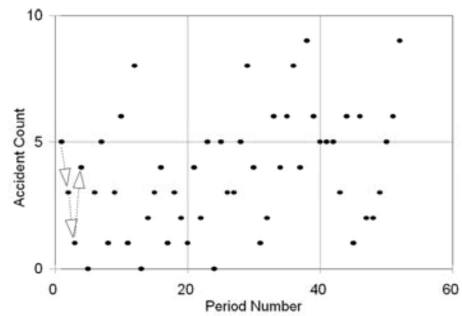
Crashes are random occurrences. The following examples demonstrate the randomness of recorded crash counts.

What is Safety?

Here is a count of injury crashes for a Freeway Segment in Colorado.
What is its SAFETY?



Here is a (monthly) count of crashes for an Intersection in Toronto.
What is its SAFETY?



Source: Dr. E. Hauer's 2013 SPF Workshop in Louisiana

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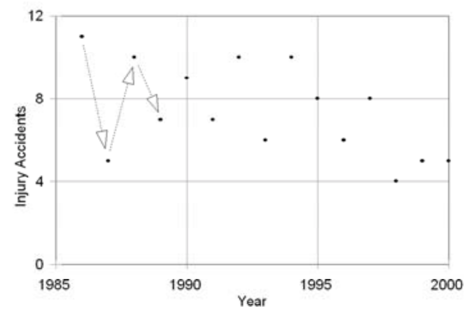
Crash counts are related to safety but their fluctuation presents a problem for safety measuring. Discuss these two charts, gradually pointing out the problems with crash counts.

What is the safety of a roadway facility?

If Safety = Crash Counts, it would mean that safety improved from 1986 to 1987, deteriorated from 1987 to 1988 etc.

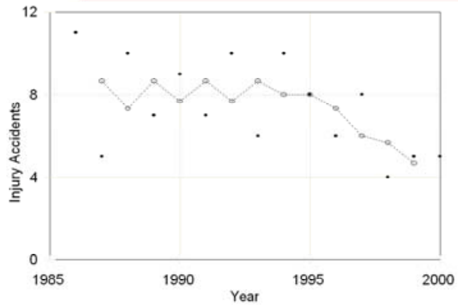


Such a definition is not correct because safety changes even if there is no change in safety-relevant roadway attributes. (Exposure, traffic control, physical features, user demography, etc.)

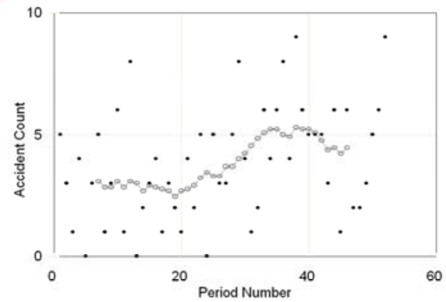
Source: Dr. E. Hauer's 2013 SPF Workshop in Louisiana

Make sure students understand why crash count does not equal safety.

We need a definition of the safety (for a roadway facility) such that, as long as the 'safety-relevant' attributes of the facility do not change, it's 'safety' does not change.



Three period running averages; Freeway Segment, Colorado



Thirteen period running averages, Intersection, Toronto

One can rightly imagine that behind the fluctuations there is a gradually changing safety property that is some kind of average

Source: Dr. E. Hauer's 2013 SPF Workshop in Louisiana

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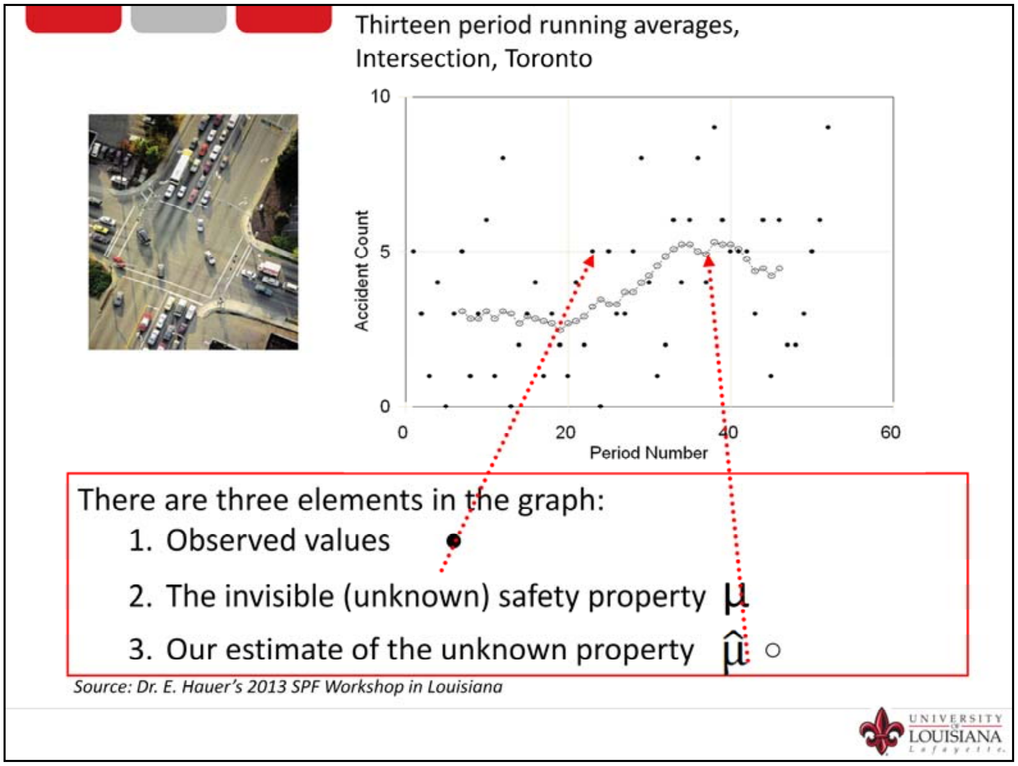
Important points:

Crash counts do not equal safety but crash count does reflect safety if it is carefully treated.



Guide students through the discussion on treatment of crash counts.

San Francisco Example with 1,072 intersections

TABLE D1
ILLUSTRATING THE REGRESSION TO THE MEAN PHENOMENON

No. of Intersections With Given No. of Accidents in 1974–76	Accidents/ Intersection in 1974–76	Accidents/ Year/ Intersection in 1974–76	Accidents/ Year in 1974–76 for Group (rounded)	Accidents in 1977 for Group	Accidents/ Intersection in 1977	% Change
256	0	0	0	64	0.25	Large increase
218	1	0.33	72	120	0.55	67%
173	2	0.67	116	121	0.70	Small increase
121	3	1.00	121	126	1.04	Small increase
97	4	1.33	129	105	1.08	-19%
70	5	1.67	117	93	1.33	-20%
54	6	2.00	108	84	1.56	-22%
32	7	2.33	75	72	2.25	-3%
29	8	2.67	77	47	1.62	-39%

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Reference: “Observational Studies” by Ezra Hauer

- Intersections with large crash rates during 74-76 experienced the rate decreasing
- Intersections with small rate during 74-76 experienced an increase in crash rate
- Average crash rate for all years remained constant of 1.1/year/intersection

TABLE D1
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54	6	2.00	108	84	1.56	–22%
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crashes/year/group in period 74-76	crashes/year/group in 1977	reduction	Actual reduction
108	72	36	12 (why)

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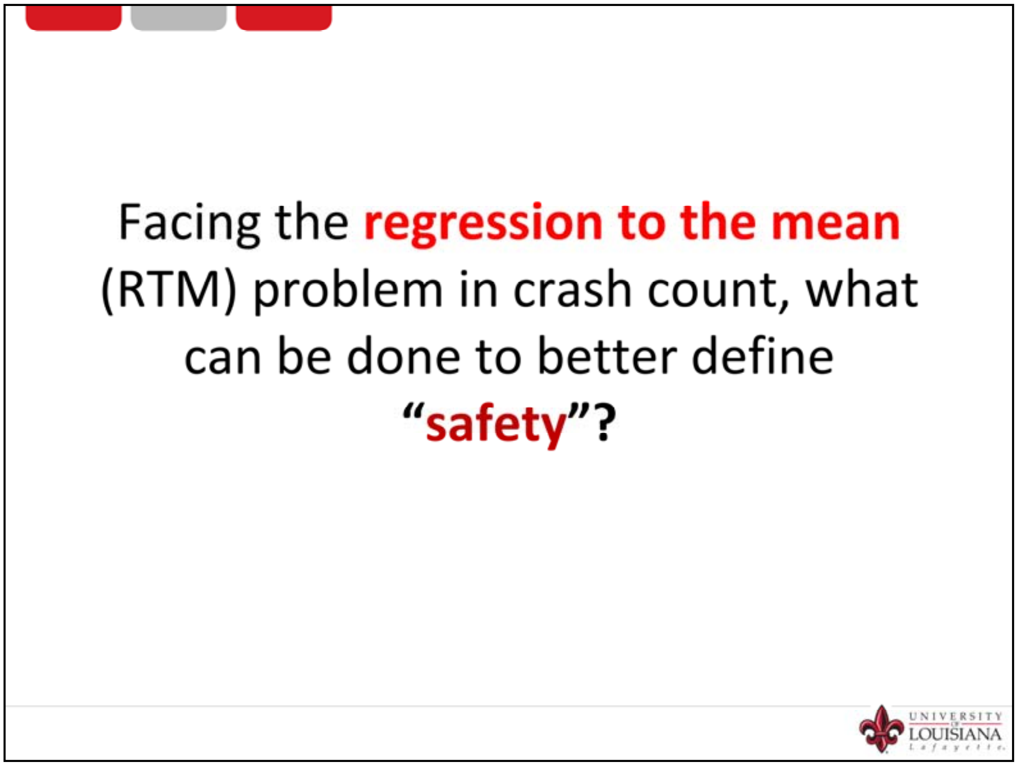
To demonstrate the magnitude of the problem, imagine that the 54 intersections with 6 crash in 3 years were treated at the end of 1976 and recorded, for example, a total of 72 crashes in 1977. A conventional before and after comparison would estimate the treatment effect as a reduction of 108-72=36 per year. However, the reduction due to RTM alone would have been 24 crashes per year



Now it is time to ask students the question.

Definition

Safety of a roadway facility (segment, intersection and etc..) is the number of crashes by kind and severity, **expected** to occur on it in a specified period of time. It will always be denoted by μ and its estimate by $\hat{\mu}$

Crash type	Crash Severity		
	PDO	Injury	Fatal
Rear-end	3.10	1.70	0.20
Angle	1.40	0.90	0.10
Single-vehicle	0.30	0.10	0.02
Pedestrian		0.05	0.03

Discuss the word “expected” first to refresh students’ statistic knowledge.

The ‘safety’ of a roadway facility generally depends on

- Roadway characteristics (design variables)
- Traffic control devices
- Level of utilization (exposure)
- Vehicle technology
- User characteristics (human factors and behavior)

All the above will be discussed later

Discuss in general how safety can be different at different roadway facilities, different locations, different time.

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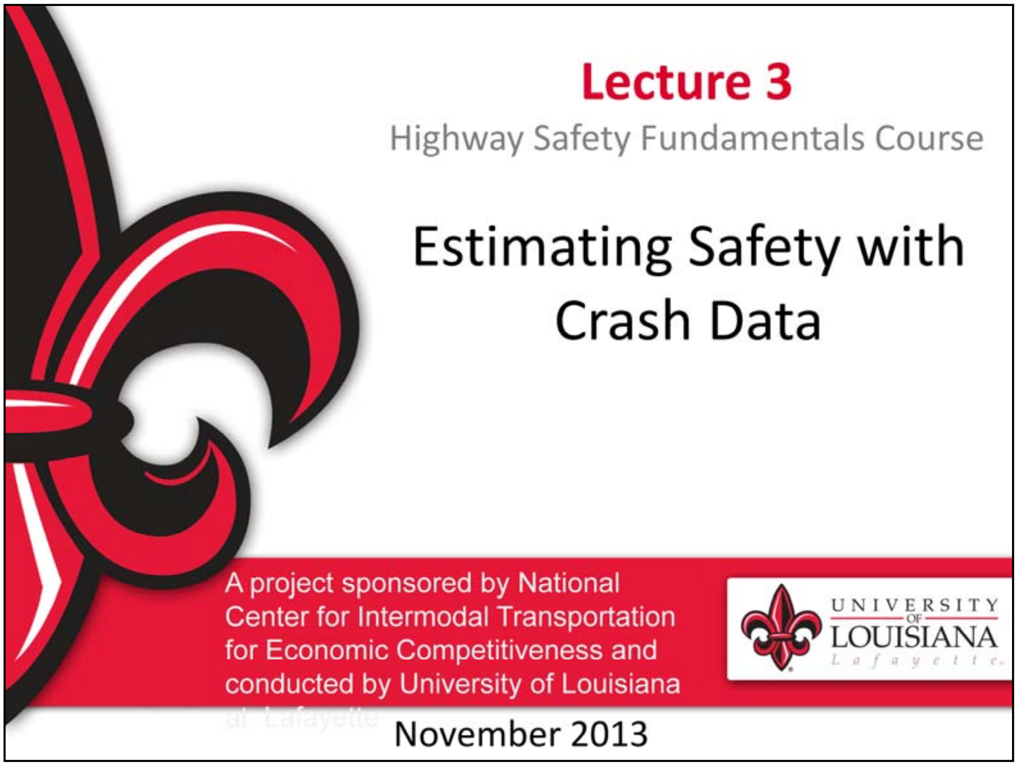


The purpose of this lecture is two-fold:

1. Understand how the crash data can be used to measure safety.
2. Understand the issues related to crash counts.

Measuring Safety

1. Issues of data quality
2. Direct measures
3. Surrogate measures
4. Predictive measures of safety

With a scientific definition of safety, now it is time to see how to measure safety in practice. In order to estimate the “expected” we need data, crash account (by severity and type) per time unit for a specific roadway fatality.

1. Issues of crash data quality

Crashes as the basis for estimating safety

- Definition and reportability
- Reportable crashes
- Injury crashes
- Reported crashes
- Integration of crash reports

First, attention may be paid to the basis (crash data collection). There are problems in crash data collection.

Definition and Reportability

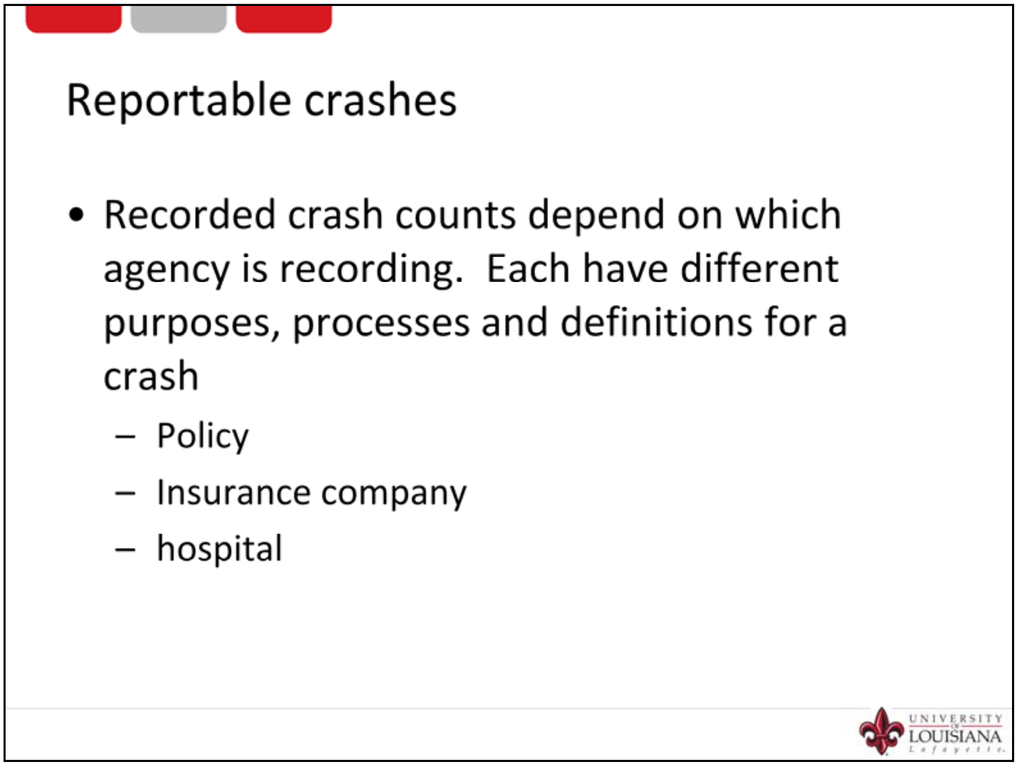
"an accident that involves a transport vehicle in transport, in which the first harmful event is not produced by the discharge of a firearm or explosive device, and that does not directly result from a cataclysm." by The American National Standard ANSI 16.1

First of all, what is a crash?

Explanation

- An unstabilized situation which includes at least one harmful event
- An unstabilized situation is a set of events not under human control
- It originates when control is lost and terminates when control is regained
- A 'harmful event' is an occurrence of injury or damage

Explain "harmful event."



Not all crashes are reported due to various reasons. For example, in Louisiana crashes involving animals are not all recorded.

- Transportation agencies typically use police crash records. The crashes in these records are defined as ‘reportable crashes’.
- Various criteria serve to define the ‘reportability’ of property-damage-only or non-injury crashes.
- There are different definitions of reportable crashes. The different definitions need to be identified in order to understand their effect to the crash counts.

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In the U.S. different state uses different threshold for “reportable crashes.”

Some states require recording all crashes with more than $300 estimated damages, other $1,000 or different numbers.

Who can accurately estimate damages?

Injury crashes and KABCO scale

- The American National Standard ANSI D16.1-1996 defines injury as “bodily harm to a person.” ‘Injury’ is further broken down as follows:
  - **K-**‘Fatal injury’ is “an injury that results in death”
  - **A-** ‘Incapacitating injury’ is “any injury, other than a fatal injury, which prevents the injured person from walking, driving or normally continuing the activities the person was capable of performing before the injury occurred”

Let student get familiar with KABCO terms.

B- 'Non-incapacitating evident injury' is "any injury, other than a fatal injury or an incapacitating injury, which is evident to observers at the scene of the accident in which the injury occurred"

C- 'Possible injury,' is "any injury reported or claimed which is not a fatal injury, incapacitating injury or non-incapacitating evident injury" and includes "claim of injuries not evident"

O- No Injury/Property Damage Only (PDO).

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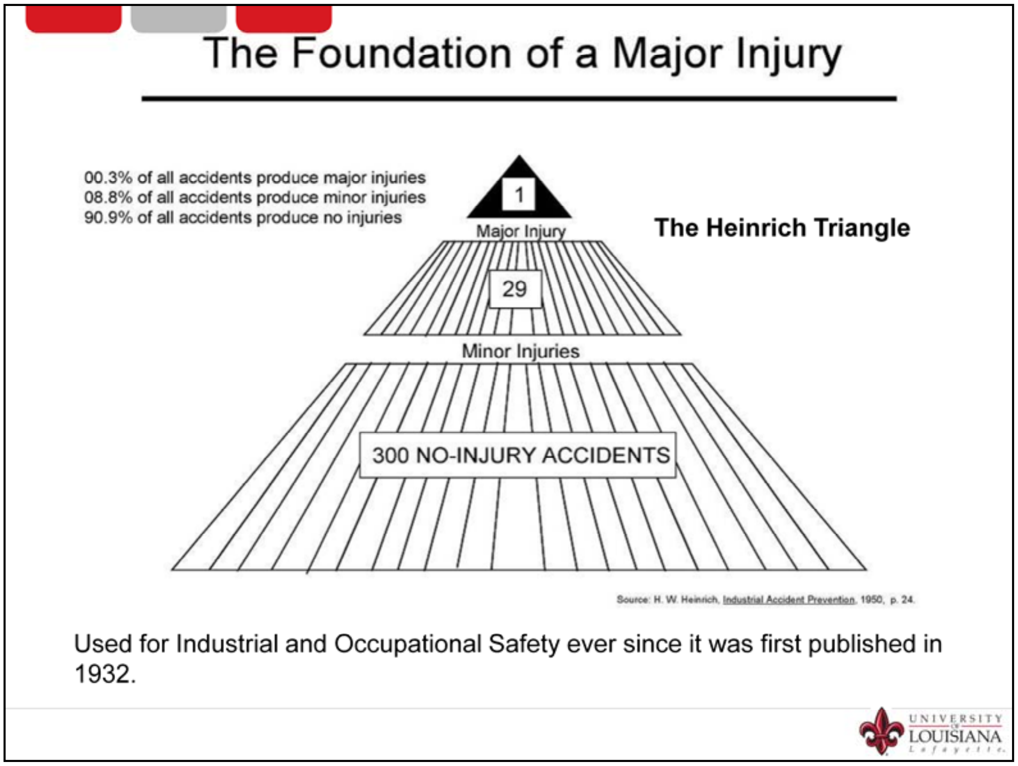


There are two basic ideas:

1. Events of lesser severity are more numerous than more severe events, and events closer to the base of the triangle precede events nearer the top
2. Events near the base of the triangle occur more frequently than events near the triangle's top, and their rate of occurrence can be more reliably estimated

It is now known that for many circumstances, such as pedestrian crashes to seniors, almost every accident leads to injury. For these circumstances, the "No Injury crashes" layer is much narrower than the one shown in the Figure.

Furthermore, it is also known that, for many circumstances, preventing events of lesser severity may not translate into a reduction of events of larger severity. An example is the installation of a median barrier where the barrier increases the number of injury crashes due to hits of the barrier, but reduces fatalities by largely eliminating cross-median crashes. In the case of median barriers, the logic of Heinrich Triangle' does not apply because the events that lead to fatalities.

Ref: H. W. Heinrich, Industrial Accident Prevention, 1950, p. 24.

Reported crashes

- Road users do not report all reportable crashes to the police
- The number of crashes that are not reported is mostly unknown and is expected to vary from jurisdiction to jurisdiction
- Police, hospital and insurance agencies maintain databases of crashes

Again, reported crashes varies by several factors.

Count of reported crashes varies by:

- Crash types
- # of people and # of vehicles involved
- Severity (the more severe the accident, the more likely it is to be reported)
- Occurrence time
- Reporting agencies

In general, fatal crashes, crashes involving more people, and crashes on major streets patrolled by state troops are more likely to be reported.

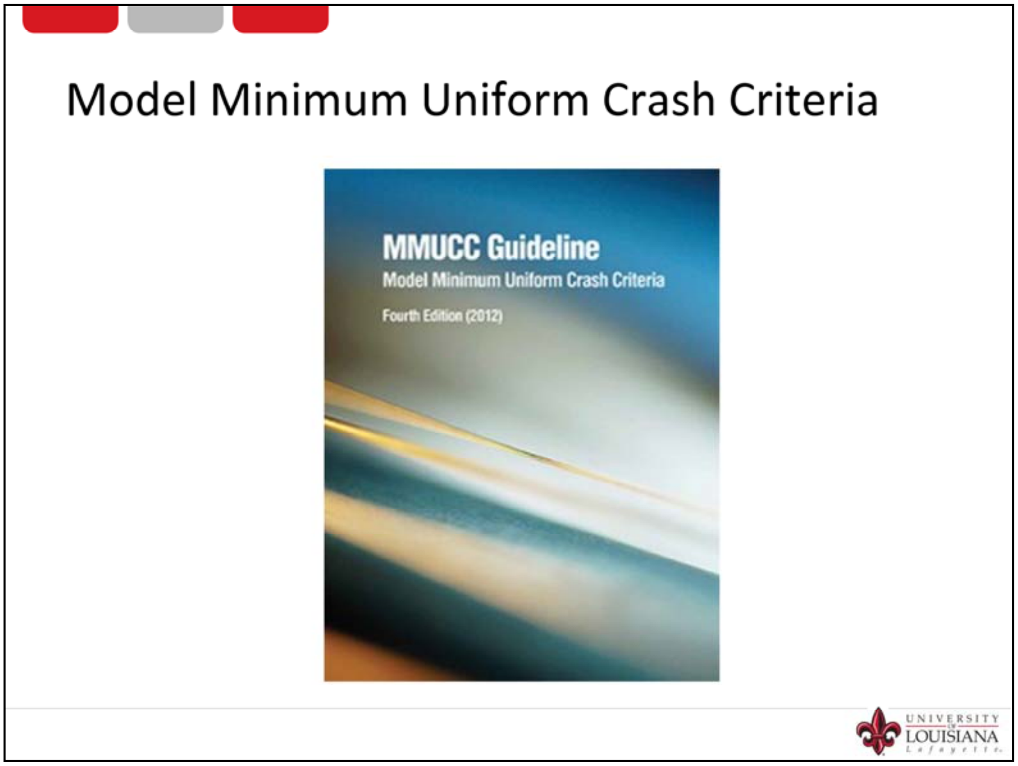
The numbers may not be completely accurate but they do reveal the problem.

- The definition of a fatal injury is also a factor. A fatal injury is defined by some agencies as "any injury that results in death within a specified period after the road vehicle accident in which the injury occurred" For general use in the administration of highway safety programs, the specified period is 30 days. However, the World Health Organization procedures, adopted for vital statistics reporting in the United States, use a 12-month limit.

How to define a crash fatality? Victim died instantly, or within certain number of days (7, 30 or 100?)

Electronic data collection technology traffic safety data. Vehicle sensors, long-range radar, optical sensors, lane detection404 and the vehicle event data recorder (EDR) systems will provide data about crash avoidance and causation. The changes in vehicle speed before and at the time of the crash, the principal direction of force and the exact latitude and longitude of the crash location will be collected in conjunction with the vehicle’s automatic crash notification (ACN) and global positioning systems (GPS). Infrared or “smart card” technology will scan or swipe electronic driver license and vehicle registration data into a handheld device, such as a Personnel Data Assistant (PDA), tablet, clipboard, or laptop. The handheld device will directly access the driver and vehicle in a few seconds.

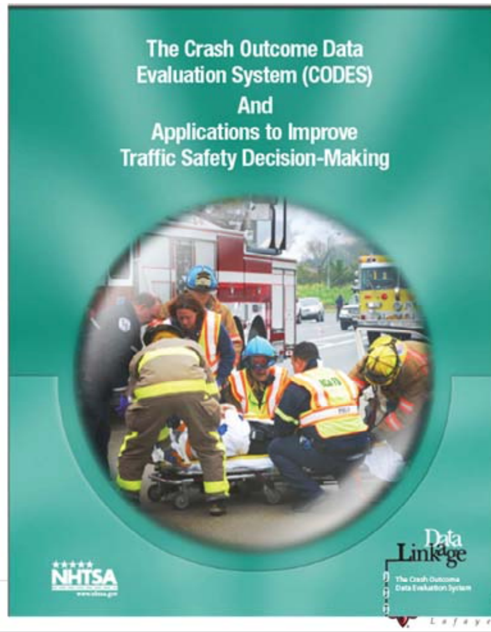
The handheld device will generate the case number, date, time, and latitude/longitude when the crash report is initiated. EDR data will be entered along with the "swiped or scanned" license and registration data. Drop-down menus, optical character recognition, speech recognition, intelligent screens and other technologies as well as linkage to other appropriate databases, such as the roadway database, and built-in logical and validity data edits will ensure accuracy. Driver and vehicle data will be simultaneously uploaded or downloaded into a mobile data terminal to update the history files at the State DMV...



FHWA, Federal Motor Carrier Safety Administration, Research and Innovative Technology Administration, and NHTSA have jointly developed the (MMUCC). The purpose of these criteria is “to provide a data set for describing crashes of motor vehicles that will generate the information necessary to improve highway safety.”

Integration of Crash Reports

- Crash Outcome Data Evaluation System (CODES) has been instrumental in working toward the integration of data collected by different agencies within a jurisdiction.

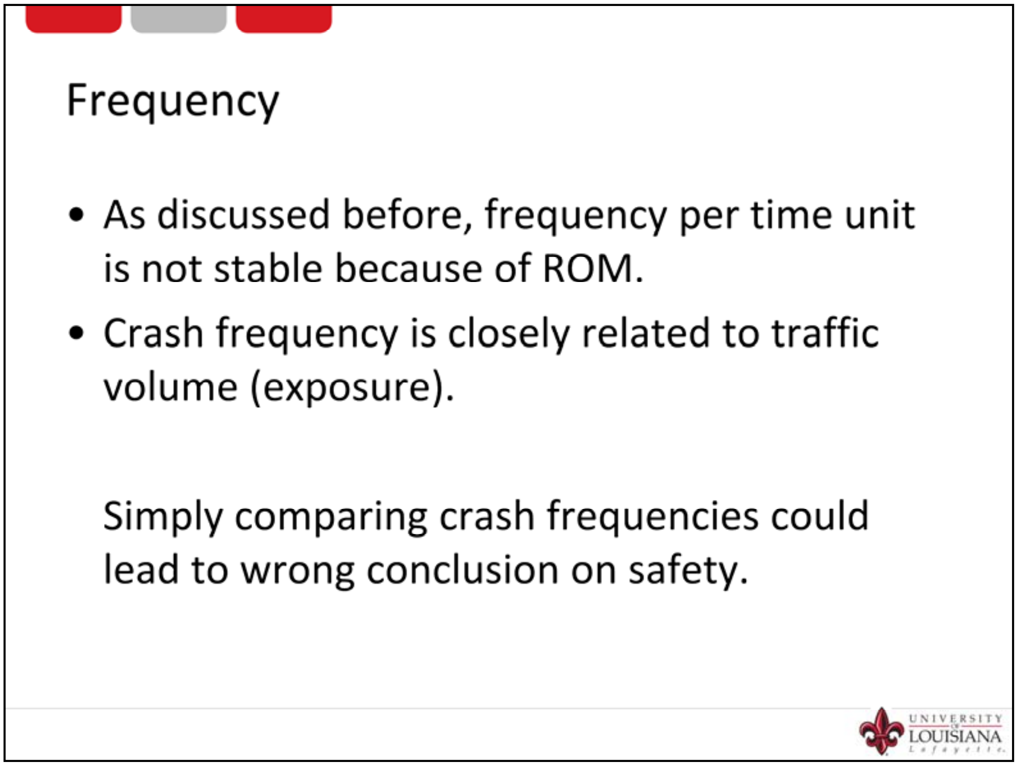


Agencies from emergency service, medical service, enforcement and etc. This has resulted in enhanced and more comprehensive information about reportable crashes.

2. Direct Measures of Safety

- Frequency
  - Random occurrence of crashes and regression-to-the-mean
- Crash rate
  - Non-linear relationship between frequency and traffic volume

Again discuss ROM and Non-linear relationship between crash frequency and AADT



Few real world examples can be introduced here to demonstrate the points.

Considering traffic volume

Crash Rate

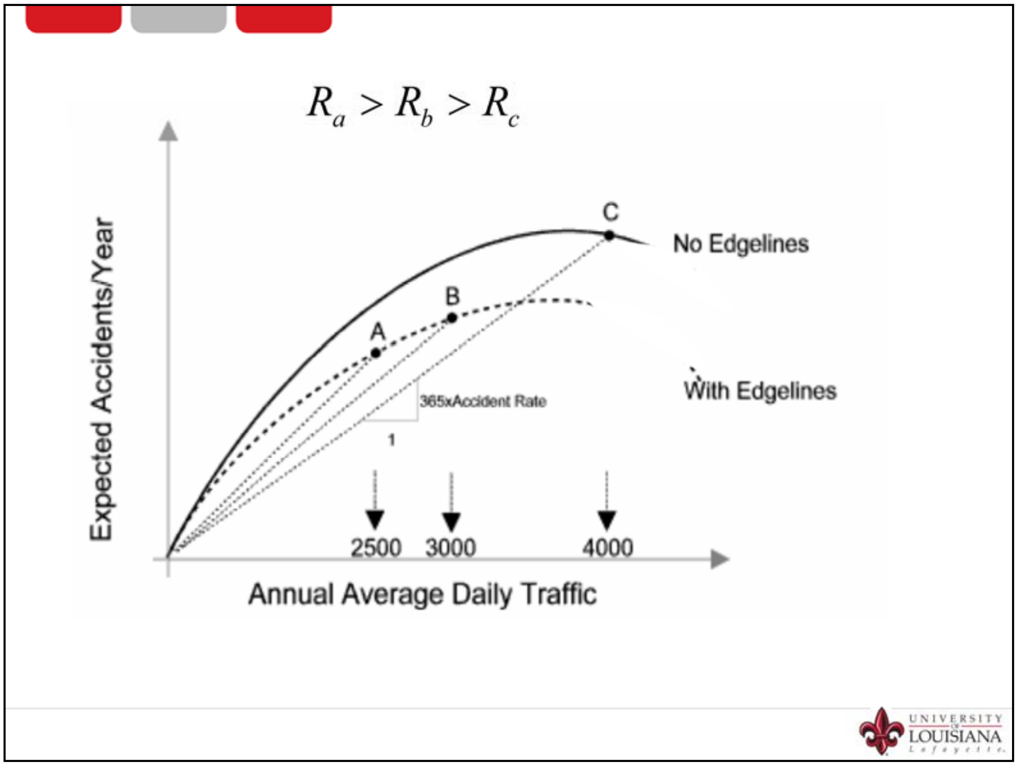
$$R = \frac{\text{Crash frequency}}{\text{Exposure per unit time}}$$

$$R = \frac{N}{365 * ADT * L} 10^6$$

$$R_f = \frac{N_f}{365 * ADT * L} 10^9$$

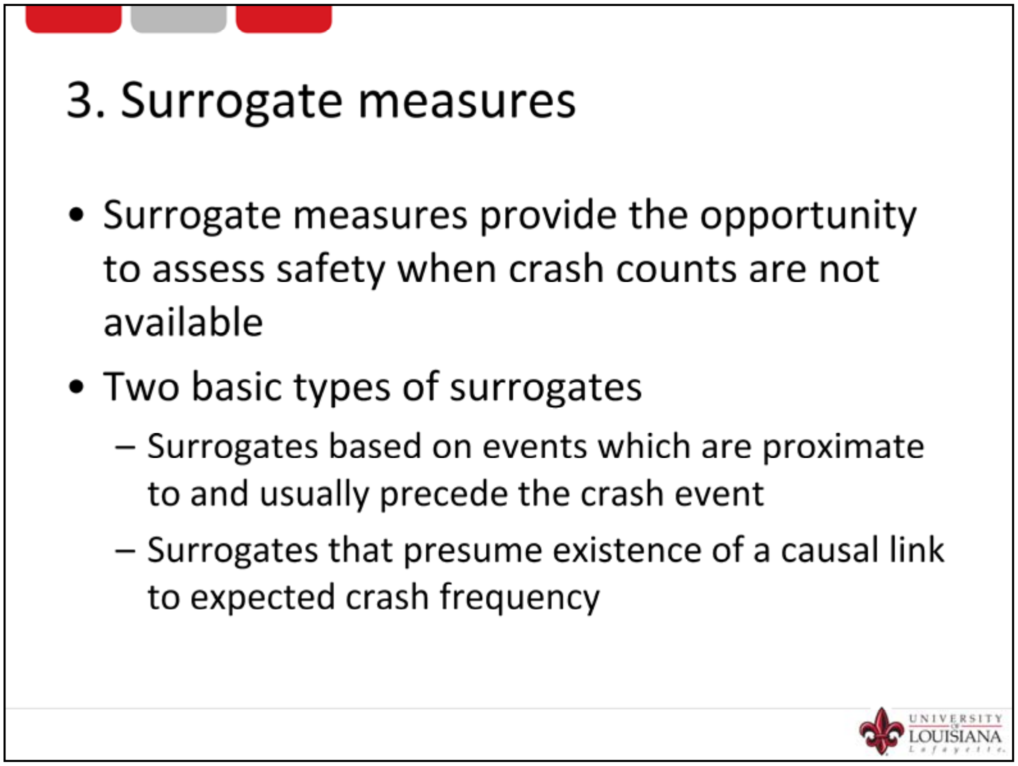
Unit: Fatalities per 100 million VMT (vehicle miles traveled)

Now let's consider volume.



However, rate also has its weakness in application.

Point A and point B could represent the same segment of road where no treatments were implemented from year 1 to year 2. However, the traffic volume on this road segment increased from 2,500 veh/day (point A) to 3,000 veh/day (point B) from year 1 to year 2. It is noted that at point B, the expected accident frequency is higher and the accident rate is lower when compared with point A. The decrease in accident rate means that, from an individual driver's point of view, travel in year 2 was safer than in year 1 because the probability of being in an accident has diminished. However, the road has not become safer as a result of higher traffic volumes.



These surrogates assume knowledge of the degree to which safety is expected to change when the surrogate measure changes by a given amount. For example, number of conflicts.

Relationship between number of expected crashes and number of surrogate events

$$\hat{\mu} = \sum_i \hat{C}_i \hat{p}_i$$

Where:

$\hat{\mu}$ = the safety of a roadway or facility estimated by means of surrogate events

$\hat{C}_i$ = estimate of the rate surrogate event occurrence for the roadway or facility for each severity class i. The estimate is obtained by field observation, by simulation, or by analysis

$\hat{p}_i$ = estimate of the crash/surrogate event ratio for the roadway or facility for each severity class i. The estimate is the product of research that uses data about the occurence of surrogate events and of crashes on a set of roadways or facilities

Surrogate Measures at Intersections

Surrogate Measure	Description
Encroachment Time (ET)	Time duration during which the turning vehicle infringes upon the right-of-way of through vehicle.
Gap Time (GT)	Time lapse between completion of encroachment by turning vehicle and the arrival time of crossing vehicle if they continue with same speed and path.
Deceleration Rate (DR)	Rate at which through vehicle needs to decelerate to avoid accident.
Proportion of Stopping Distance (PSD)	Ratio of distance available to maneuver to the distance remaining to the projected location of accident.
Post-Encroachment Time (PET)	Time lapse between end of encroachment of turning vehicle and the time that the through vehicle actually arrives at the potential point of accident.
Initially Attempted Post-Encroachment Time (IAPT)	Time lapse between commencement of encroachment by turning vehicle plus the expected time for the through vehicle to reach the point of accident and the completion time of encroachment by turning vehicle.
Time to Collision (TTC)	Expected time for two vehicles to collide if they remain at their present speed and on the same path.

The accuracy of the events listed in above in predicting expected crashes has not been fully proven.

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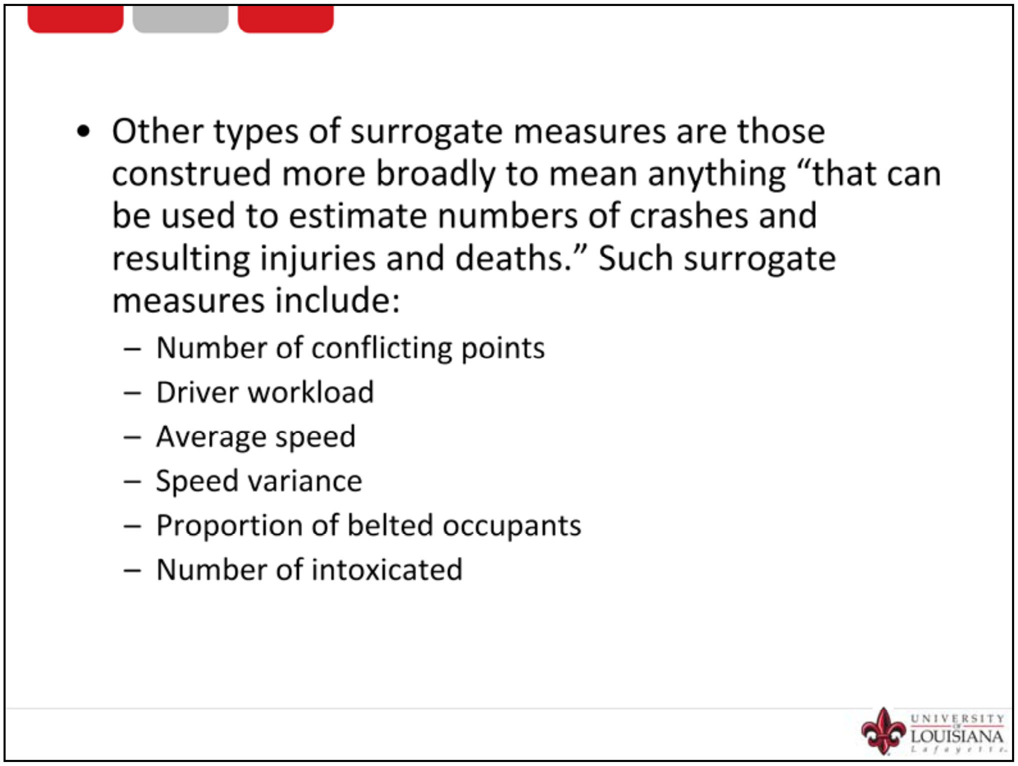
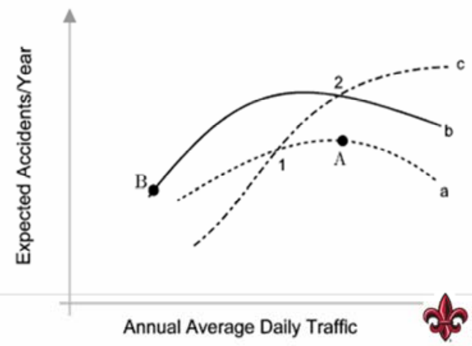
Ref: http://www.fhwa.dot.gov/publications/research/safety/03050/03050.pdf



The challenge is to establish quantitative relationship between surrogate measures and safety. And these relationships could vary by location (local culture and drivers' mentality).

4. Predictive measures of safety

- Safety Performance Functions (SPFs) typically express the objective relationship between the expected number of crashes by type and severity and a host of variables (traffic volume, design variables)



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For example, it is possible to establish an SPF between the expected frequency of single-vehicle crashes and the AADT for two-lane rural roads. This SPF predicts the average number of single-vehicle crashes on a two-lane rural road with a given AADT. SPFs may also express the relationship between the expected number of crashes and AADT and many more factors alternatively called “variables” or “covariates” (More on SFP later).

For questions contact

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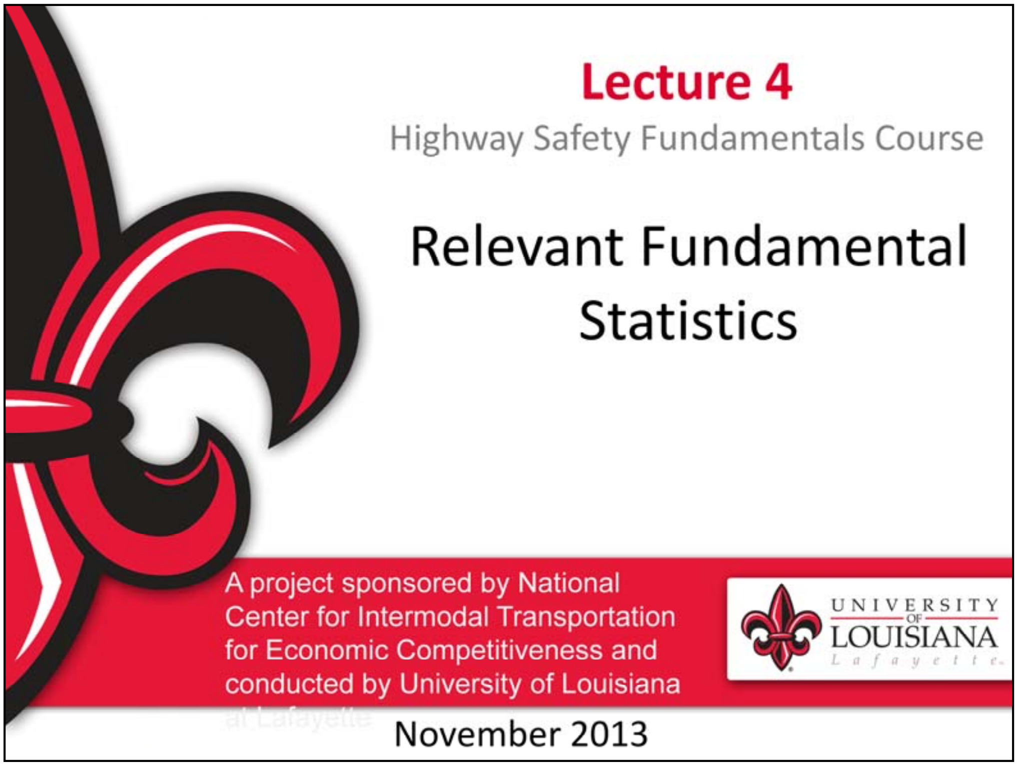


Refresh fundamental statistics related to safety analysis. It is critical to apply and develop the statistical method correctly for safety analysis. If you look at highway safety in any transportation textbook (published 5 years ago), you will see the statistical highway safety analysis methods that are no longer used in today highway safety analysis.

Remember the saying “Lies, damn lies, and statistics.”

Outline

- Fundamental Statistics
  1. Basic terms
  2. Accuracy and standard error
  3. Probability distribution functions
     a. Poisson distribution
     b. Binomial distribution
     c. Negative Binomial distribution
  4. Empirical Bayes Method
  5. Safety model Goodness-of-Fit evaluation

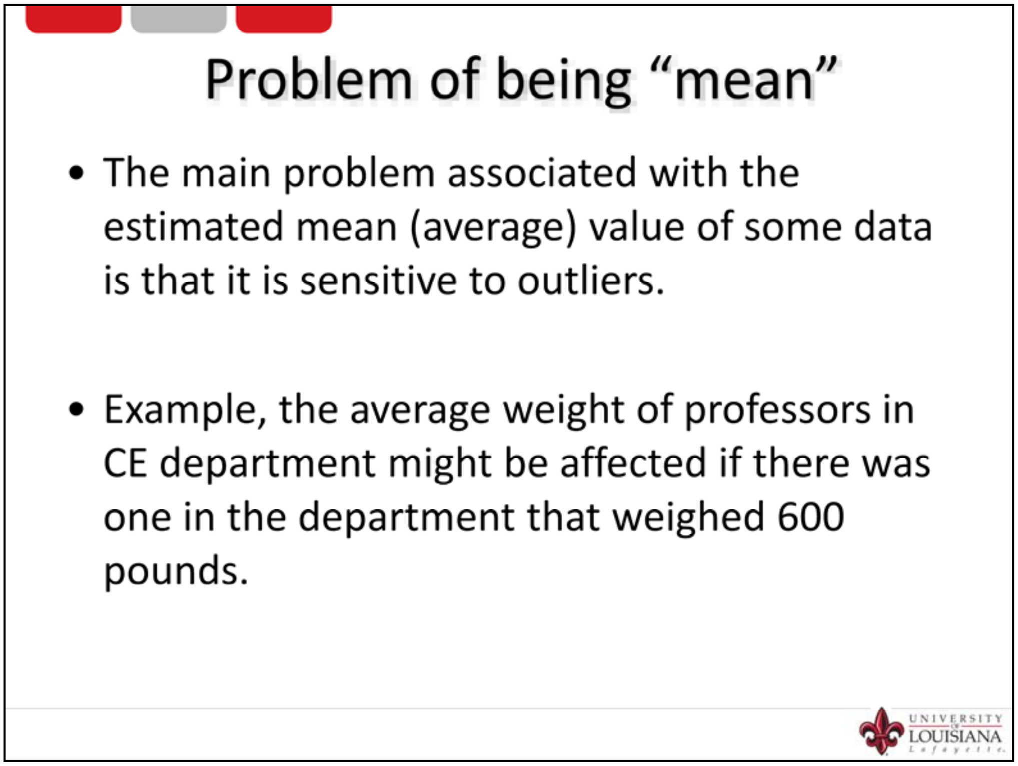
The purpose of this lecture is to refresh student knowledge on some fundamental statistics, which is key in safety analysis and modeling.

1. Basic terms

Mean

- In statistics, mean has two related meanings:
  - the arithmetic mean
  - the expected value of a random variable, which is also called the population mean.
- Arithmetic average is often used to estimate population mean

$$\bar{x} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i$$

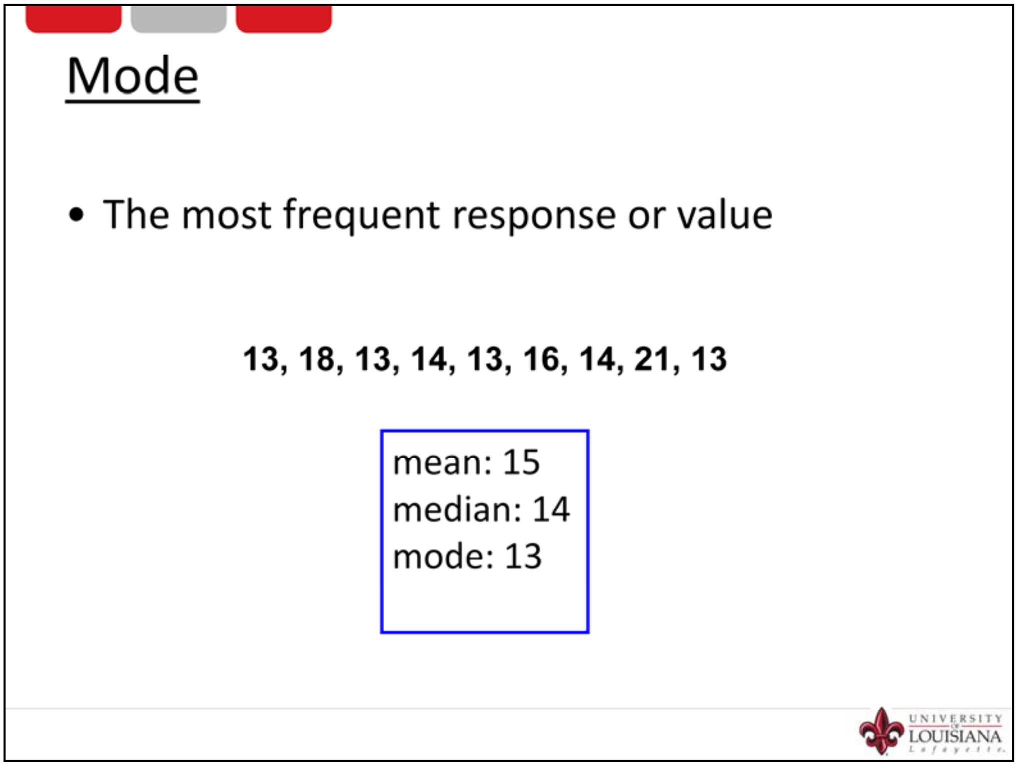


- To see how "outlier" affects the sample statistics

Median

- Because the mean average can be sensitive to extreme values, the median is sometimes useful and more accurate.
- The median is simply the middle value (by ranking order and choose middle value. If even then average between two in the middle).

Outliers have minimum, or if any, effect on median.



Outliers have minimum, or if any, effect on mode also.

- How things change by outlier

13, 47, 13, 14, 13, 16, 14, 21, 13

mean: 18.1
median: 14
mode: 13

Variance

- In statistics, the **variance** of a probability distribution is one measure of dispersion, averaging the squared distance of its possible values from the expected value.
- Whereas the mean is a way to describe the location of a distribution, the variance is a way to capture its scale or degree of being spread out.

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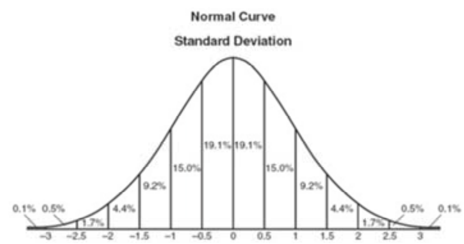
- If the underlying distribution is not known, then the sample variance may be estimated by standard error as:

$$s_N^2 \equiv \frac{1}{N} \sum_{i=1}^{N} (x_i - \overline{x})^2,$$

not an unbiased estimator

$$s_{N-1}^2 \equiv \frac{1}{N-1} \sum_{i=1}^{N} (x_i - \overline{x})^2.$$

bias-corrected sample variance



Property of variance (a quiz)

- Variance is ________ because the squares are positive or zero.
- If all values of a random variable are equal, then its variance is ___.
- In a finite population or sample, if some elements of the variable are unequal, then the variance is larger than __.
- In a finite population, if the list is extended with a number that is equal to the mean, then the variance decreases unless it was 0. For example, the variance of 1, 2, 3 is _______than the variance of 1, 3.

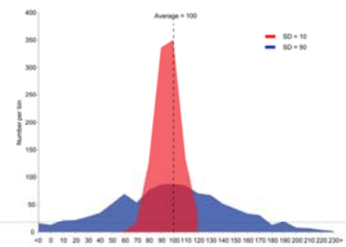
Standard Error of the Mean

$$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{N}}$$

$\sigma_{\bar{x}}$ = *standard error of the mean*

σ_x = *the standard deviation of the original distribution*

N = *the sample size*



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2. Accuracy and Precision

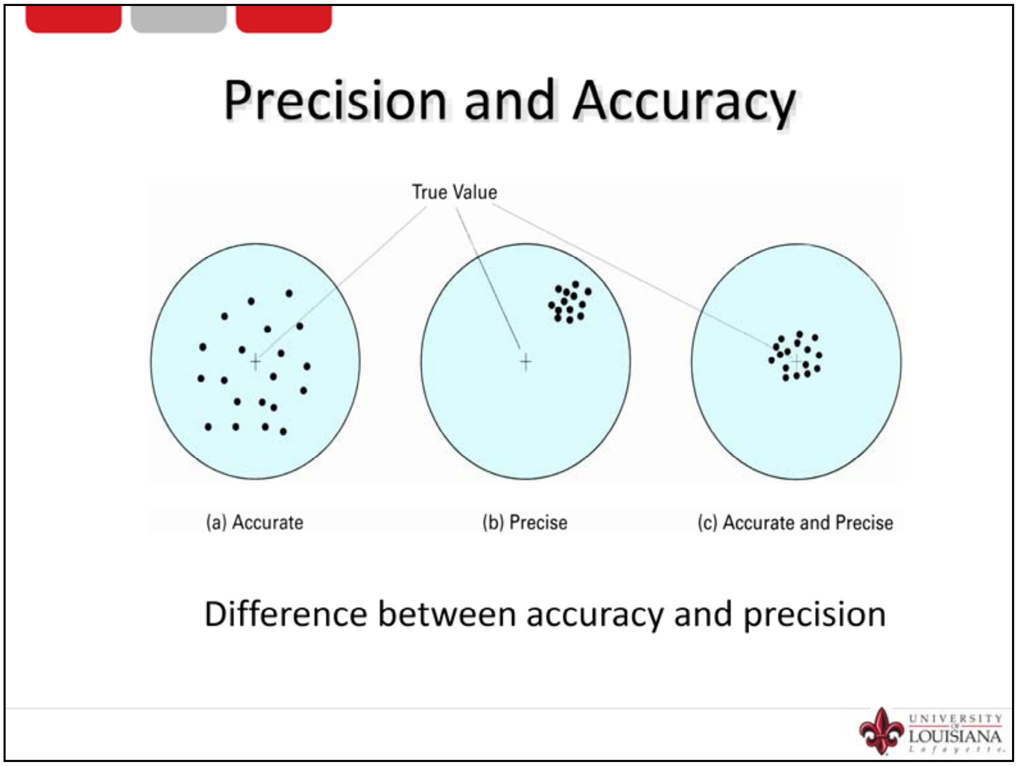
The word **accuracy** in science, engineering and statistics refers to the closeness of estimates, measurements, or observed values to their true or expected value. The ‘standard error’ is a common measure of accuracy.

As all estimates are subject to uncertainty, the accuracy of an estimate is required in order to know the relationship between the estimate and reality. This is why, as a rule, safety estimates are accompanied by a description of their accuracy.

There appear to be two different definitions of the standard error.

The standard error of a sample of sample size is the sample's standard deviation divided by square root of sample size.

The standard error of an estimate may also be defined as the square root of the estimated error variance of the quantity, as assumed here in our safety analysis



This is something that may appeal in safety modeling.

3. Distribution Functions

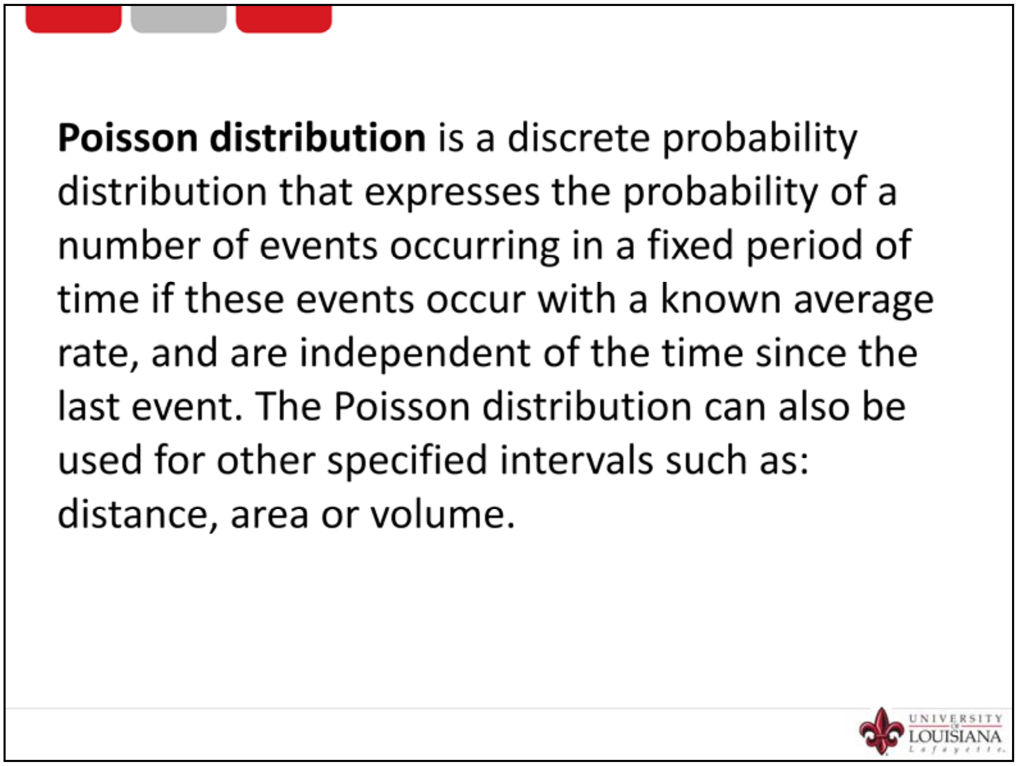
Poisson distribution

The Poisson distribution is used to model the number of events occurring within a given time interval. The formula for the Poisson probability mass function is

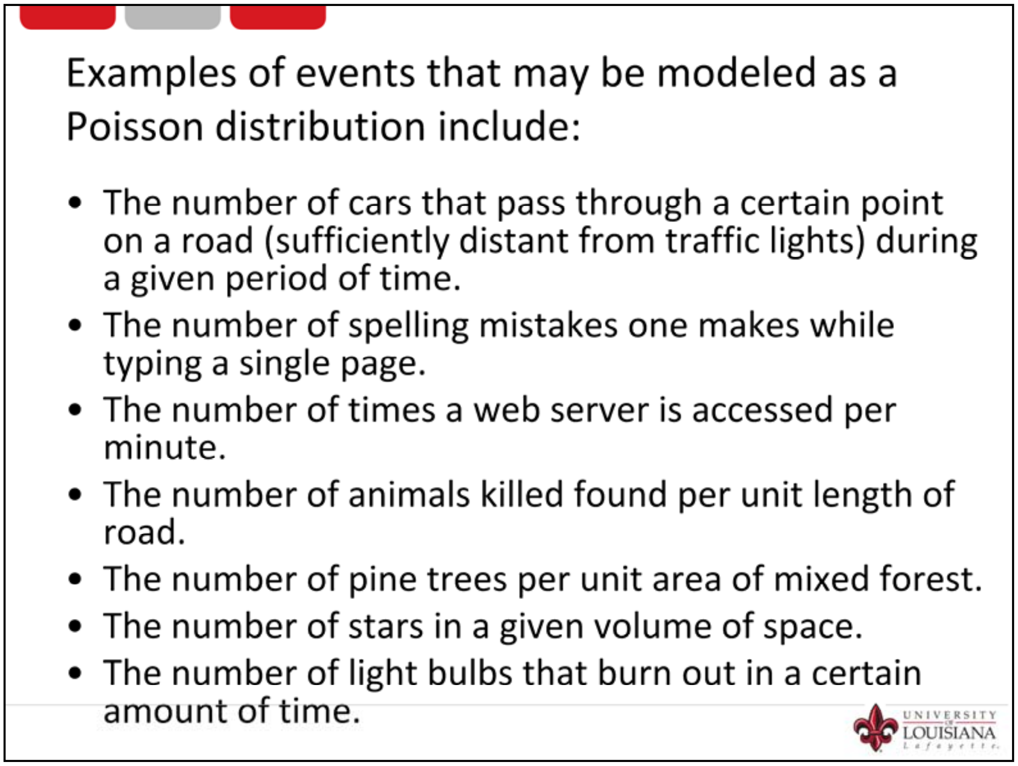
$$p(x, \lambda) = \frac{e^{-\lambda}\lambda^x}{x!} \qquad \text{for } x = 0, 1, 2, \cdots$$

λ is the shape parameter which indicates the average number of events in the given time interval.

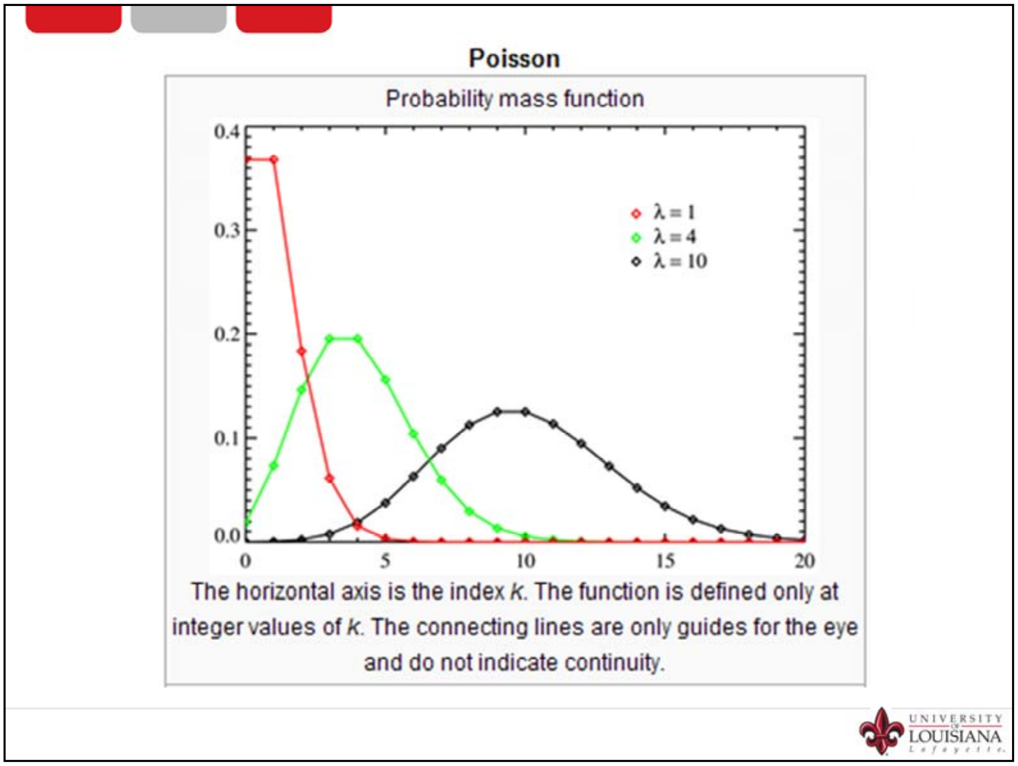
It is a commonly used distribution function for number of crashes.



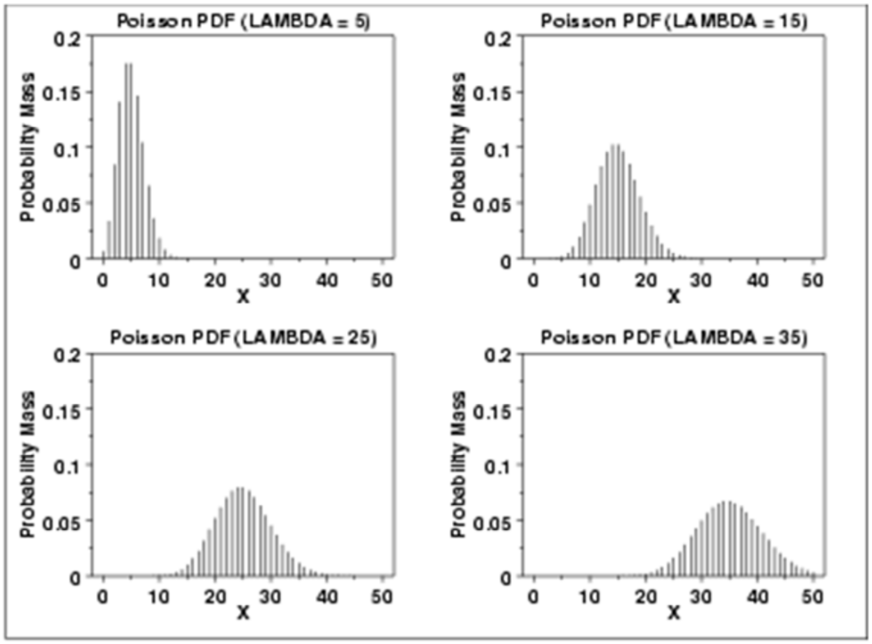
A classic example is the probability of a certain number of bombs striking a randomly selected area from a group of equally sized areas. This example was applied to German V-1 buzz bombs (a flying bomb, the precurser to the guided missile) striking South London during WW II. On paper, South London was divided geographically into 576 areas each having 0.25km2 areas. Assuming the 535 bombs launched toward South London were done so with random targeting. Therefore, the probability of any number of bombs (0 to 535) striking any area of the 576, at random, can be calculated. For use in the Poisson distribution, the mean, λ, is the quotient of number of bombs divided by number of equally sized areas.



Examples are from the Internet. The Possion distribution is best for modeling events that are highly random in nature.



Discuss how the shapes change as the mean changes.


Poisson PDF (LAMBDA = 5)
Poisson PDF (LAMBDA = 15)
Poisson PDF (LAMBDA = 25)
Poisson PDF (LAMBDA = 35)
Probability Mass
X
0
0.05
0.1
0.15
0.2
10
20
30
40
50

Binomial distribution

- **Binomial distribution** is the is a discrete probability distribution of the number of successes in a sequence of n independent yes/no experiments, each of which yields success with probability p.

Such a success/failure experiment is also called a Bernoulli experiment or Bernoulli trial. In fact, when n = 1, the binomial distribution *is* a Bernoulli distribution.

Probability mass function

- In general, if the random variable *K* follows the binomial distribution with parameters *n* and *p*, we write *K* ~ B(*n*, *p*). The probability of getting exactly *k* successes is given by the probability mass function:

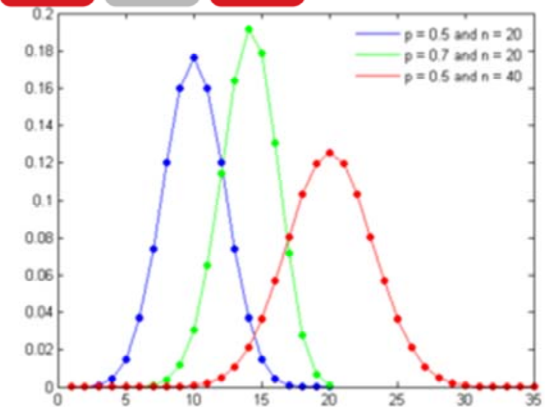
$$f(k;n,p) = \binom{n}{k} p^k (1-p)^{n-k}$$

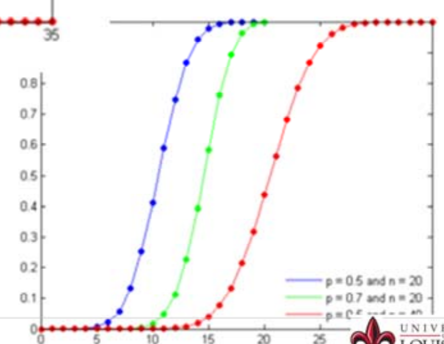
- for k = 0, 1, 2, ..., n and where

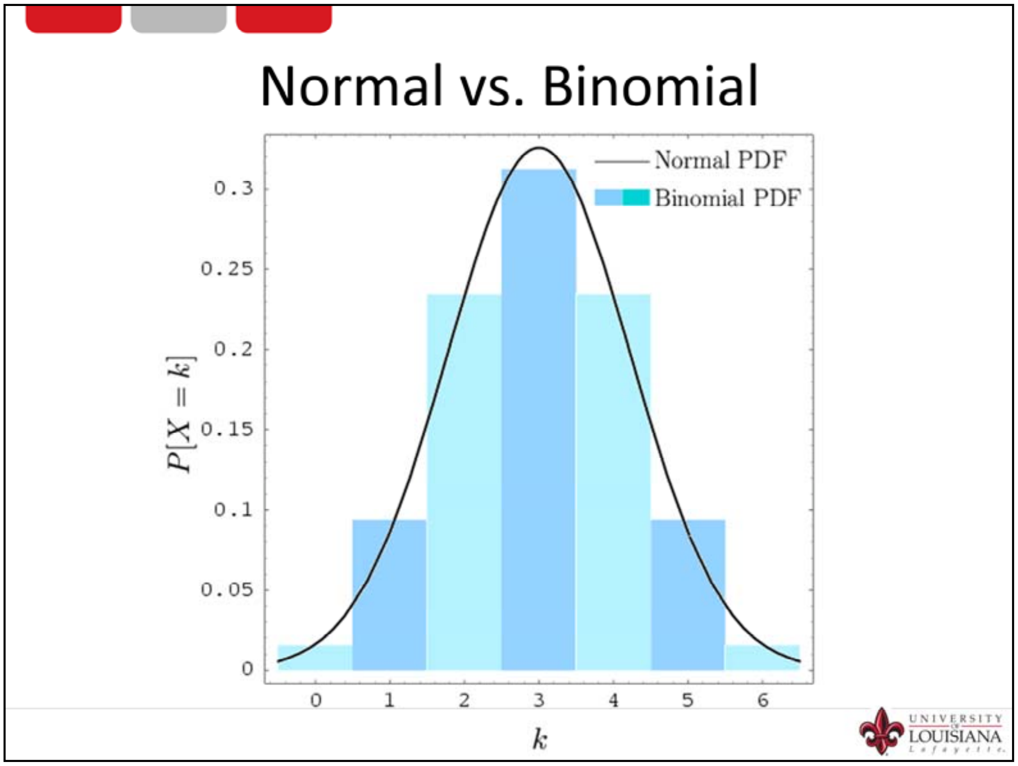
$$\binom{n}{k} = \frac{n!}{k!(n-k)!}$$

is the binomial coefficient (hence the name of the distribution) "*n* choose *k*" (also denoted $C(n, k)$). The formula can be understood as follows: we want k successes (pk) and $n - k$ failures $(1 - p)(n - k)$.

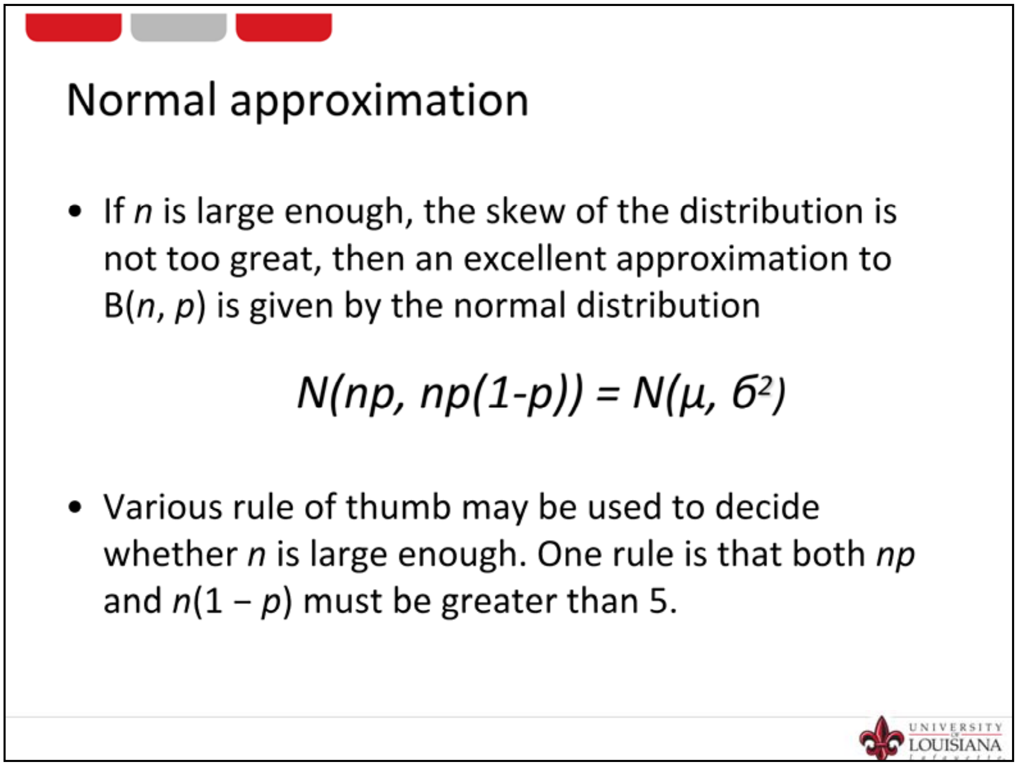
However, the k successes can occur anywhere among the n trials, and there are C(n, k) different ways of distributing k successes in a sequence of n trials.


p = 0.5 and n = 20
p = 0.7 and n = 20
p = 0.5 and n = 40


p = 0.5 and n = 20
p = 0.7 and n = 20



Ask students why is one in column and one is continuous?
Normal distribution is for continuous random variables.



However, the specific number varies from source to source, and depends on how good an approximation one wants; some sources give 10.

Poisson approximation

- The binomial distribution converges towards the Poisson distribution *as* the number of trials goes to infinity while the product np remains fixed. Therefore the Poisson distribution with parameter $\lambda = np$ can be used as an approximation to B(n, p) of the binomial distribution if n is sufficiently large and p is sufficiently small.
- According to two rules of thumb, this approximation is good if $n \geq 20$ and $p \leq 0.05$, or if $n \geq 100$ and $np \leq 10$.

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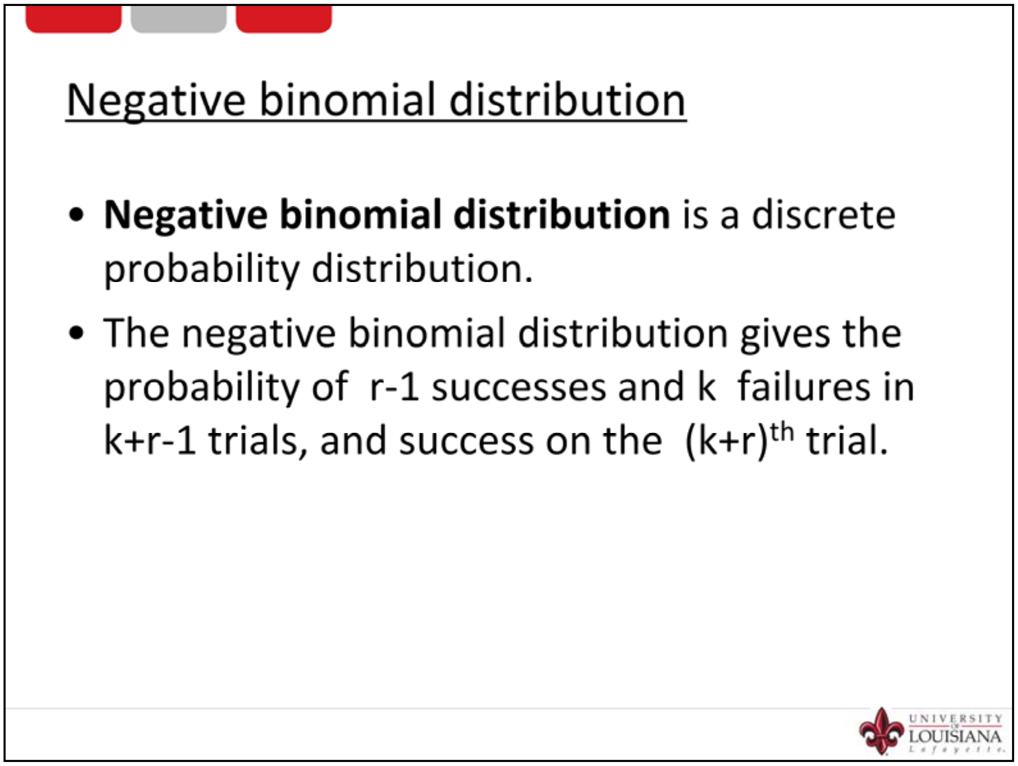


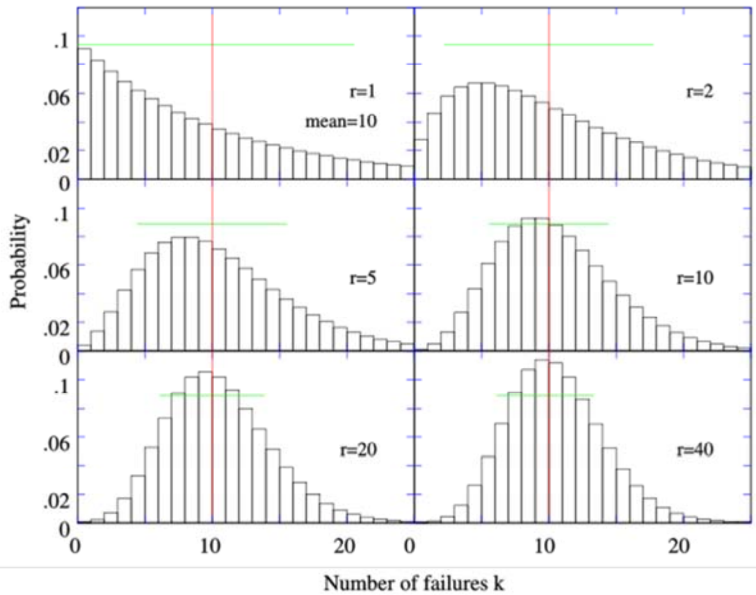
To analyze crash data in traffic safety analysis, statistical distributions are often used to fit the data. It is often assumed that the distribution of crash counts at a given site follows a Poisson distribution, which only has one parameter and its mean and variance are the same. The Poisson distribution has been shown to be reasonable to model crash data at a given one site. In reality, crash data over a series of sites often exhibit a large variance and a small mean, and display overdispersion with a variance-to-mean value greater than one. For this reason, the negative binomial distribution, also known as the Poisson-Gamma distribution, has become the most commonly used probabilistic distribution for modeling crashes. The negative binomial distribution is considered to be able to handle overdisperson better than other distributions and has been widely used in many fields in addition to traffic safety, such as entomology, zoology, bacteriology and biology.

Probability mass function

$$f(k; r, p) = \frac{\Gamma(r+k)}{k!\,\Gamma(r)}\, p^r\,(1-p)^k$$

where $\Gamma(z)$ is the gamma function

The family of negative binomial distributions is a two-parameter family. One very common parameterization employs two real-valued parameters *p* and *r* with $0 < p < 1$ and $r > 0$. Under this parameterization, the probability mass function of a random variable with a NegBin(*r*, *p*) distribution takes the following form …



r=1
mean=10
r=2
r=5
r=10
r=20
r=40
Probability
Number of failures k

Summary

Probability Function	Mean	Variance
Poisson (mean equals to variance)	λ	λ
Binomial (mean is bigger than variance)	np	np(1-p)
Negative Binomial (variance is bigger than mean)	$\frac{r(1-p)}{p}$	$\frac{r(1-p)}{p^2}$

Overdispersed Poisson

(variance exceeds the sample mean)

- If a Poisson distribution is used to model such data, the model mean and variance are equal. In that case, the observations are *overdispersed* with respect to the Poisson model.
- The negative binomial distribution can be used as an alternative to the Poisson distribution when sample variance **exceeds the sample mean.**
- Since the negative binomial distribution has one more parameter than the Poisson, the second parameter can be used to adjust the variance independently of the mean

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4. Empirical Bayes method

- **Empirical Bayes methods** are a class of methods which use empirical data to evaluate or approximate the conditional probability distribution that arise from Bayes' theorem. These methods allow one to estimate quantities (probability, average, etc.) about an individual member of a population by combining information from empirical measurements on the individual and on the entire population

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Empirical Bayes methods involve

- An "underlying" probability distribution of some unobservable quantity is assigned to each member of a statistical population. This quantity is a random variable if a member of the population is chosen at random. The probability distribution of this random variable is not known, and is thought of as a property of the population.

Empirical Bayes methods involve

- An observable quantity assigned to each member of the population. When a random sample is taken from the population, it is desired first to estimate the "underlying" probability distribution, and then to estimate the value of the unobservable quantity assigned to each member of the sample.

The Empirical Bayes method addresses two problems of safety estimation

It **increases the precision** of estimates beyond what is possible when one is limited to the use of a two-three year history crashes, and it **corrects for the regression-to-mean bias**. The theory of the EB method is well developed. The time has come for the EB method to be the standard and staple of professional practice in highway safety.

The increase in precision is important when the usual estimate is too imprecise to be useful. The elimination of the regression to mean bias is important whenever the crash history of the entity is in some way connected with the reason why its safety is estimated.

An intuitive explanation

The Empirical Bayes is based on the recognition that crash counts are not the only clue to the safety of a highway segment. Another clue is in what is known about the safety of similar sites.

Consider a novice taxi driver in New York who had no accident during his first year on the job. It is also known that an average novice taxi driver in the city has 0.08 crashes per year. It would not be correct to claim that this novice taxi driver is expected to have zero accident next year (based on his record only). It would also be peculiar to estimate his safety to be 0.08 accident/year (by disregarding his record). A sensitive estimate must be a mixture of the two clues.

The basic equation:

$$N = N_1\omega + N_2(1-\omega)$$

where *N: estimated expected crashes*

N_1: crashes expected on similar sites

(from safety performance function)

N_2: observed accident counts

w: weight factor (between zero and one)

The key is determined by how much "weight" is given to the crashes expected on the similar sites. The strength of EB method is in the use of a "weight" that is based on the sound logic and on real data.

In the first edition of Highway Safety Manual:

$$\omega = \frac{1}{1 + \frac{N_1 Y}{\varphi}}$$

Y: number of years of crash counts used

φ: overdispersion parameter

The dispersion parameter comes from a Negative Binomial Distribution. It is discovered that crash counts are usually widely dispersed than what would be consistent with the Poisson assumption.

5. Safety Model Goodness-of-fit Evaluation

- Common 'goodness-of-fit' measures (R^2, χ^2, AIC, and etc.) are overall measures expressed by a single number.
- For intended safety applications, they are insufficient.
- Examining residuals (differences between the observed and predicted) is a key part of all statistical modeling.

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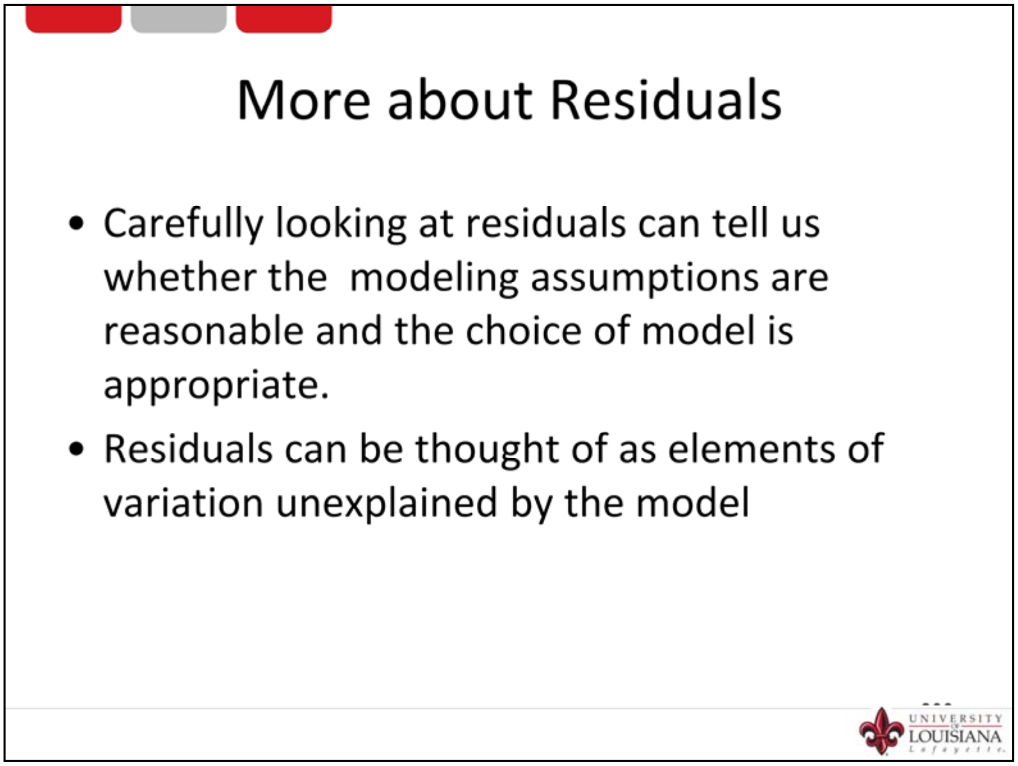
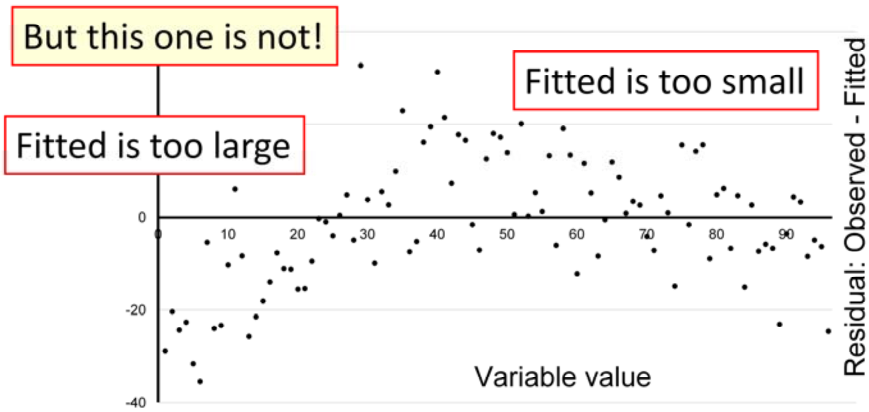
Materials in this section are mainly from the 2013 SFP workshop by Dr. Ezra Hauer.

It is critical for students understand the safety model evaluation for the application purpose.



An analyst should expect a model to err in predicting a response in a random fashion; the model should predict values higher than actual and lower than actual with equal probability. Departures from this assumption usually mean that the residuals contain *structure* that is not accounted for in the model. Identifying that structure and adding term(s) representing it to the original model leads to a better model.

A fit is thought good only if the residuals are closely packed around 0 **everywhere** for safety model applications.

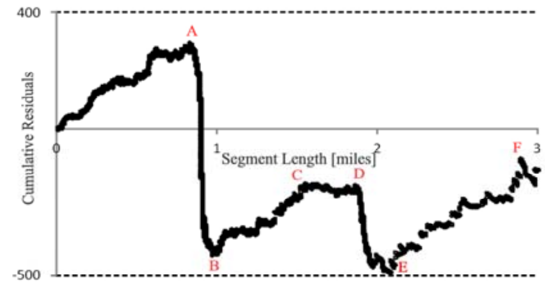


Cumulated Residual Plot (CURE)

- CURE can give more information on the model fitness by replacing chaos with clarity
- What should a good CURE plot look like?
  - **Should not have long up or down runs**
  - **Should not have vertical drops**
  - **Should meander around the horizontal axis**

What information does this CURE plot manifest?

What about this CURE?



Observed>Fitted, 0-A, B-C, E-F

Fitted>Observed, A-B, D-E

Where the drop is precipitous there may be outliers.

Summary

- Basic statistics concept
- Several commonly used probability distributions in safety modeling
- Special goodness-of-fit requirements for safety models
- To learn more Engineering Statistics at http://www.itl.nist.gov/div898/handbook/index.htm

For questions contact

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The objective of this lecture is to let students understand the purpose and history of safety models and key issues in safety model development.

Outline

- **Introduction**
- Development of Safety models
  1. Exploratory data analysis
  2. Formulating model structure
  3. Parameter estimation
  4. Model fitness evaluation

Background

- The practice of Highway or Roadway Safety is evolving from **qualitative** to **quantitative;** this evolvement is made possible by the transfer of state-of-the-art knowledge into analytical tools.

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Explain briefly how roadway safety has evolved from qualitative to quantitative. Take the ASHTO HSM as an example.

Why Safety Models

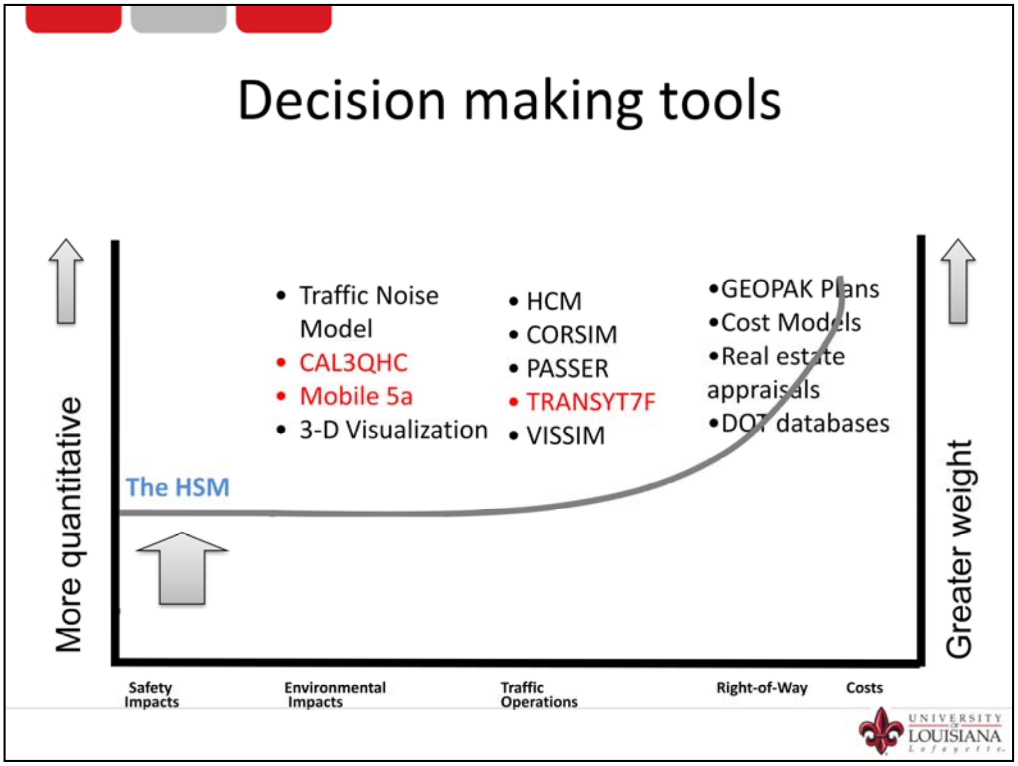
The model provides a structured methodology to estimate the expected average crash frequency (by total crashes, crash severity and type) of a site, facility or roadway network for a given **time period, geometric design and traffic control features, and traffic volumes (AADT).**

Discuss the need for safety predictive models in project decision making process.

Facing multiple options for a project, Decision Makers need to know which one is better and by how much.

We need a tool to quantify safety in decision making process.

To make a sound decision, we must weigh in on all factors. There are often conflicts between factors, for example, cost and safety.



Lack of quantitative tools for safety evaluation was a problem in the past.

CAL3QHC **Modeling Methodology for Predicting Pollutant Concentrations Near Roadway Intersections**

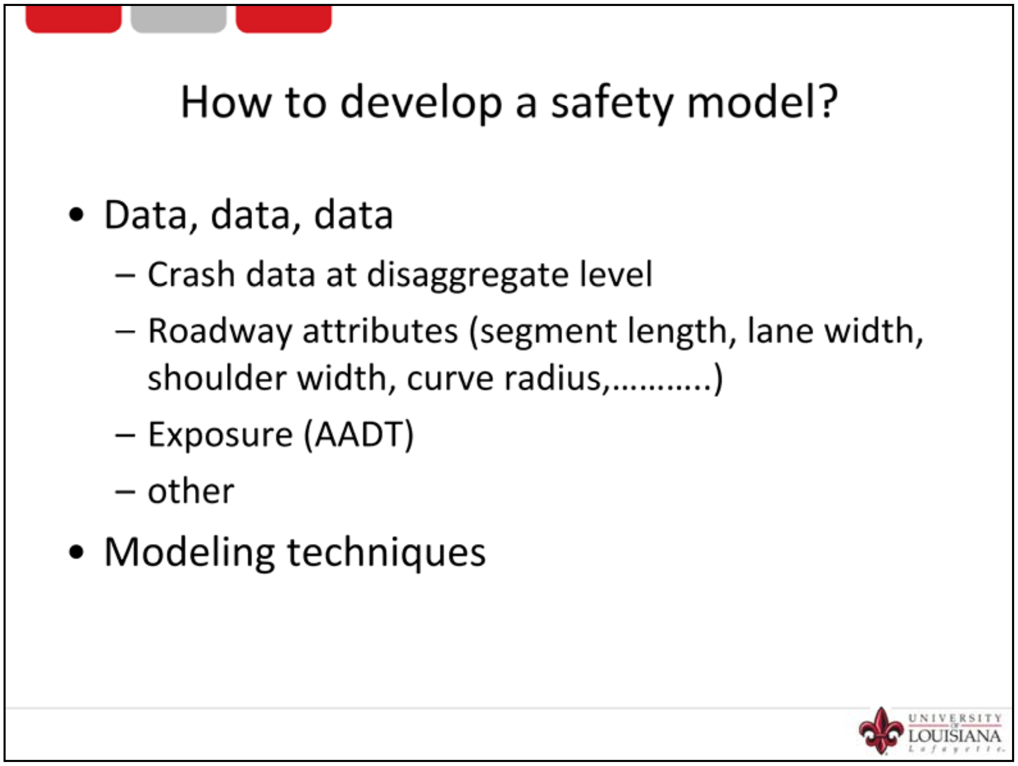
MOBILE5a - Vehicle Emission Modeling Software

CORSIM Microscopic Traffic Simulation Model

PASSER Series of programs are traffic control optimization programs designed by Texas Transportation Institute

Transyt7f Traffic Network Study Tool

VISSIM Transportation planning, traffic engineering and traffic simulation



Two key elements in safety model development: data (availability and accuracy) and modeling techniques.

Two Modeling Directions

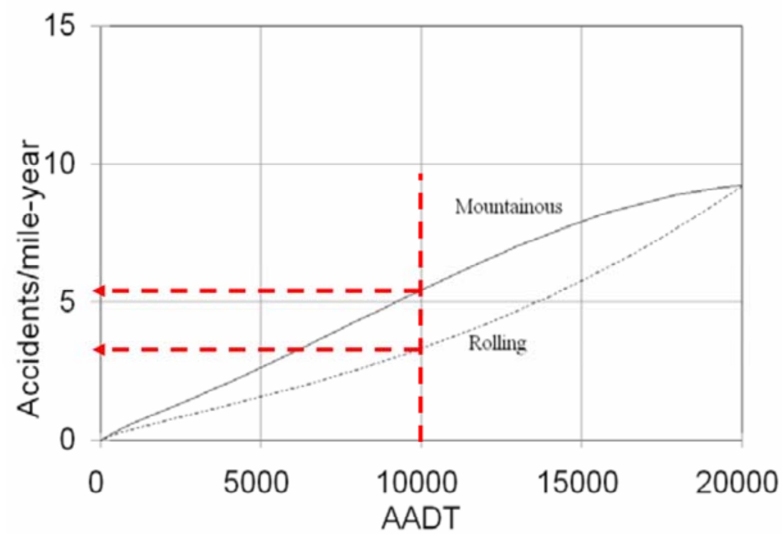
$$\mu = AADT \times L \times (\beta_0 + \sum \beta_i X_i)$$

Pros and Cons

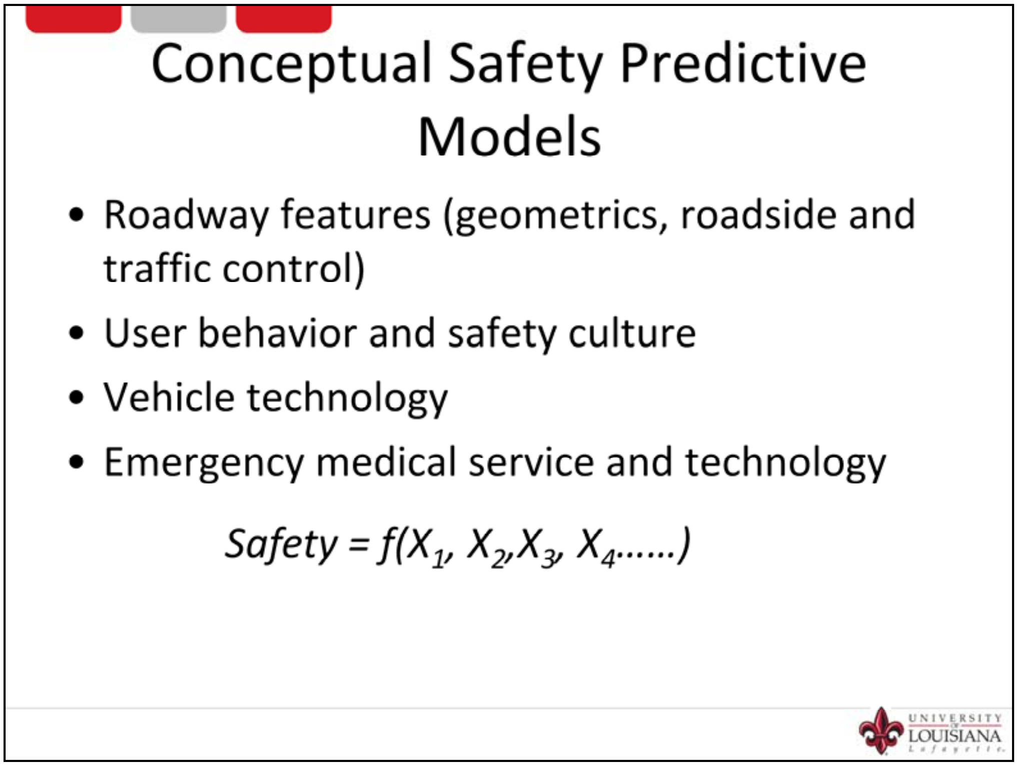
	Parametric	Nonparametric
Advantages	1. More efficient and sensitive when assumptions are met. 2. Simple to formulate and faster to compute.	1 . Fewer assumptions, thus distribution free 2. No parameters to estimate 3. Can handle any kind of data.
Disadvantages	1. If assumptions are incorrect, results of parametric methods can be very misleading. 2. Not always robust. 3. Difficulties arise in handling categorical data.	1. Less sensitive than parametric methods when the parametric models' assumptions are met. 2. Less efficient than parametric methods when assumptions are met. 4. Requires larger database and difficult to calculate.

A thorough discussion on the two different modeling techniques is needed here with examples prepared by instructors in his/her familiar research areas.

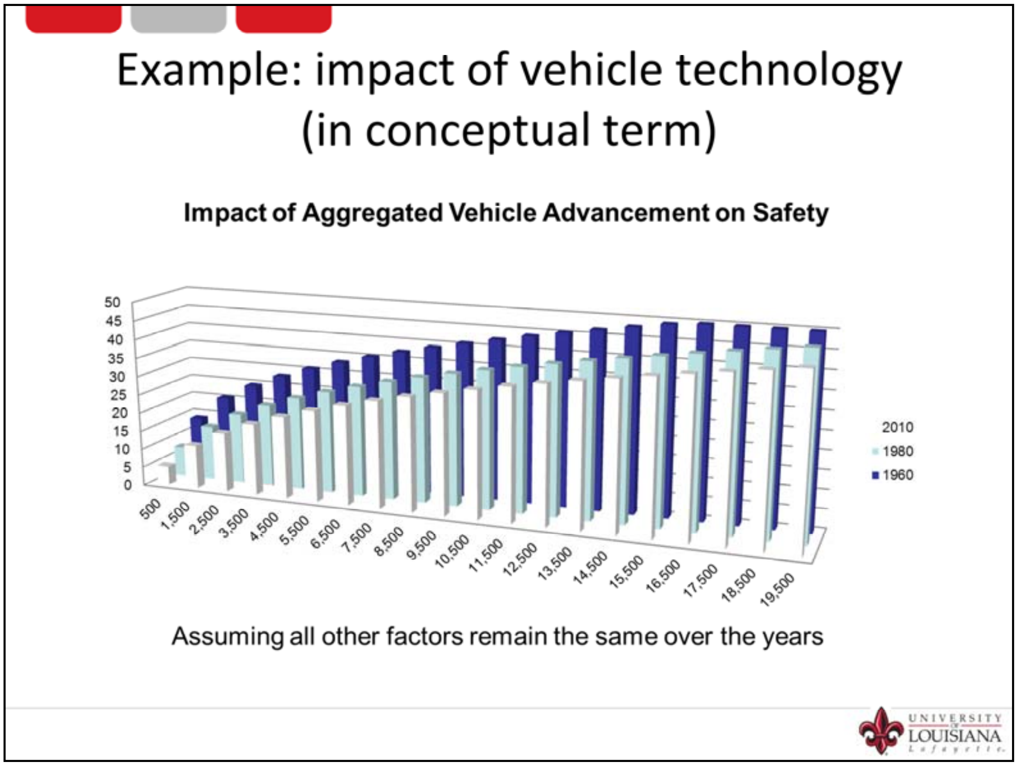
Example of a parametric safety predictive model



Here is an example from parametric safety model. It demonstrates the quantitative difference in expected crash numbers between two roadways under different terrains.



Ideally, a safety model should include all crash contributing factors as discussed in the introduction.

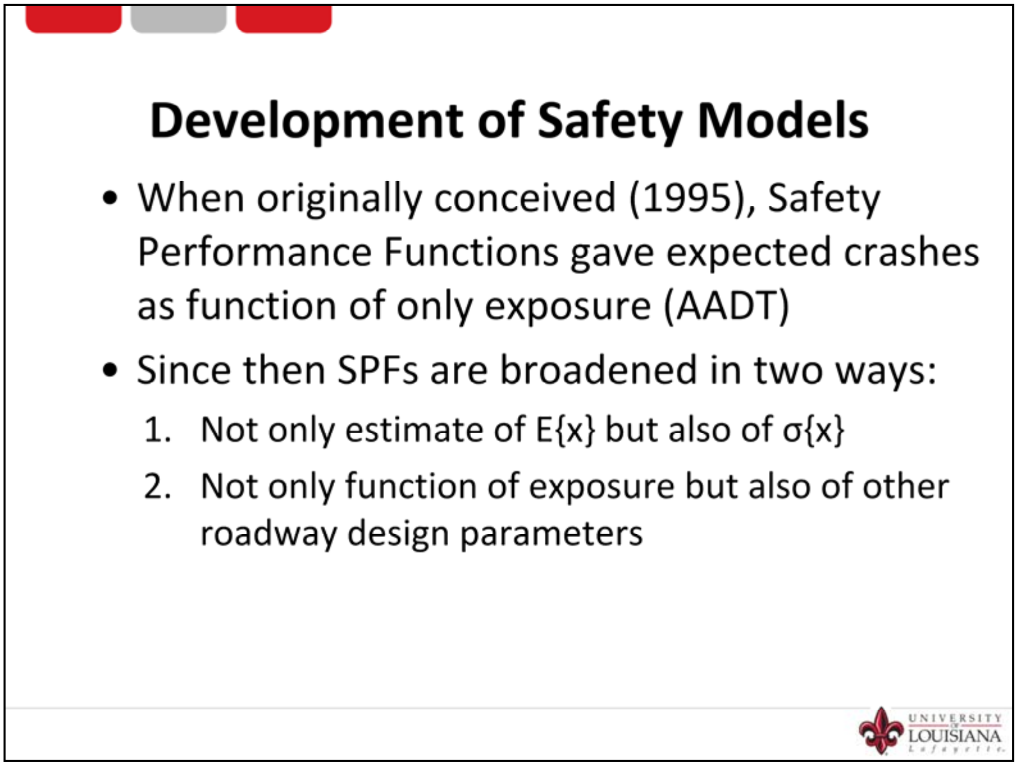


We know for sure vehicles today are much safer than vehicles 10, 20, 30, 50 years ago. All vehicle safety features today are collectively making a (huge) difference on crashes occurrences and severity. But it is hard to independently estimate the impact quantitatively.

Ask students “Any suggestions from you?”

Safety Modes

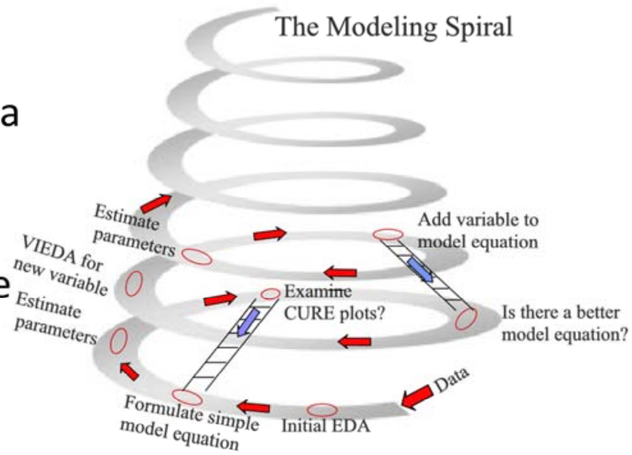
- Introduction
- **Development of Safety models**
  1. Exploratory data analysis
  2. Formulating model structure
  3. Parameter estimation
  4. Model fitness evaluation



For the safety models, we have to focus on roadway feature now (lack of data from other E areas).

Basic Steps in SPF Development

1. Data cleaning
2. Exploratory data analysis
3. Formulating model structure
4. Parameter estimation
5. Model fitness evaluation



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The spiral chart is from Dr. Huaer's workshop on Highway Safety Models conducted in 2013 (at Washington D.C. and Louisiana). The remaining lecture on this topic is mainly from his workshop except the data analysis example.

1. Data Cleaning

- Ideally, modelers need perfect data on crash and roadway features
  - Crash characteristics and location
  - Roadway characteristics
- But in real world, data is never 100% accurate
  - Miscoding
  - Missing information
- Data cleaning is the key first step

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This issues has been discussed in previous lecture.

Safety models are built from data. The transformation of data into a model is the work of a modeler.

Which variables to use?
Equation form?
How to estimate parameters?
Does it fit?
Add a variable?

The modeler has to make a variety of choices: what traits (variables) to use to define the populations, what functions to use for combining the variables into a model equation, what should be minimized of maximized to obtain a good fit, how can the fit be improved, which data points are outliers, etc. These choices depend on the exercise of insight. This section is about developing initial insight into what the data suggest.

2. Exploratory Data Analysis (EDA)

- Is there an orderly relationship between a variable and E{m}?
- If yes, what function can represent it?
- A good start in safety modeling depends on
  - Data
  - Experience
  - Computation skills
  - Judgment

EDA is an approach to understanding the message of data. More on the next slide.

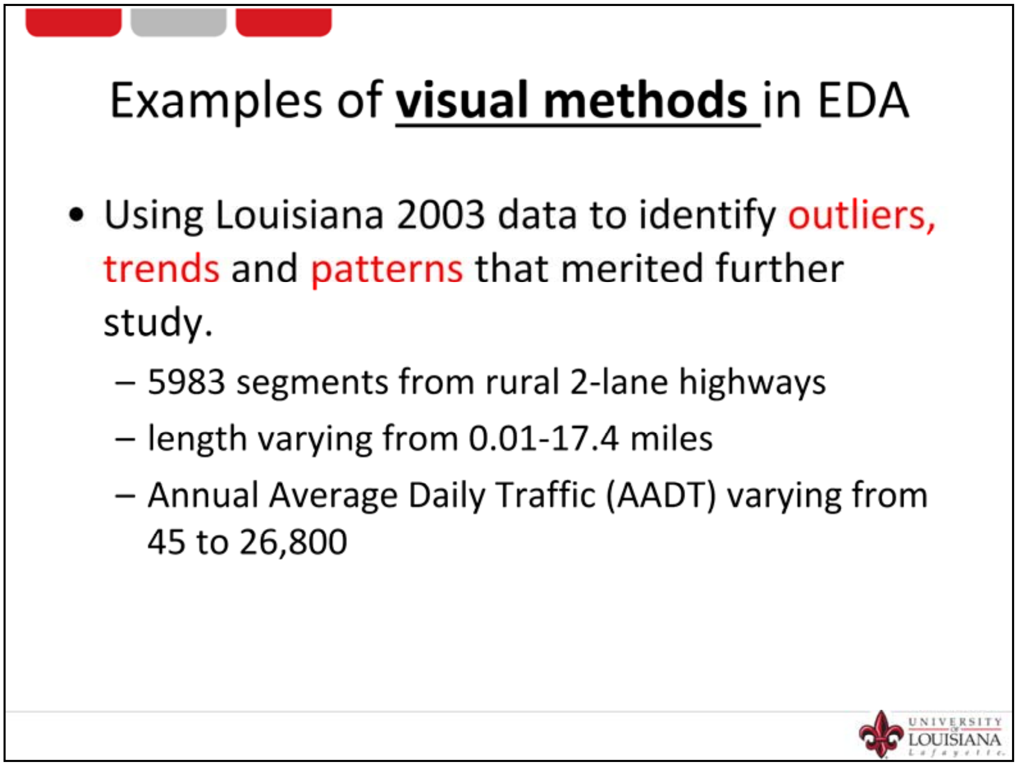
By Wikipedia

- In statistics, **exploratory data analysis (EDA)** is an approach to analyzing data sets to summarize their main characteristics, often with **visual methods**. A statistical model can be used or not, but primarily EDA is for seeing what the data can tell us beyond the formal modeling or hypothesis testing task. Exploratory data analysis was promoted by John Tukey.

More specifically, EAD is set to:

- maximize insight into a data set
- uncover underlying structure
- extract important variables
- detect outliers and anomalies
- test underlying assumptions
- help in developing parsimonious models

EDA is a popular data exploring step used by data modeling people in all fields.



Rural two-lane highways in Louisiana carry one-third of the total vehicle miles traveled (VMT) and have experienced a considerably high percentage of fatal crashes. There were12,467 crashes on rural two-lane highways in Louisiana in 2010.

Sample of the data

LENGTH	ADT	PAVE_WIDTH	SHOU_WIDTH	TOT_ACC	INT_ACC
1.85	3300	24	6	0	0
0.14	3300	24	6	0	0
0.53	3300	24	8	1	0
1.69	4800	24	6	3	0
0.11	4800	24	0	0	0
0.06	3300	24	0	0	0
0.63	4300	24	6	0	0
1.03	4300	24	7	0	0
0.56	8600	24	8	0	0
1.23	5000	24	9	1	1
0.36	5000	24	15	0	0
0.23	9900	24	14	2	2
1.06	9900	24	9	1	0
4.45	4100	24	8	6	3
0.42	1850	24	4	1	0
7.6	1850	24	7	0	0
0.7	1430	24	7	0	0
0.05	1430	24	11	0	0
0.42	2800	24	7	0	0

Questionable value

Discuss why these data are questinable.

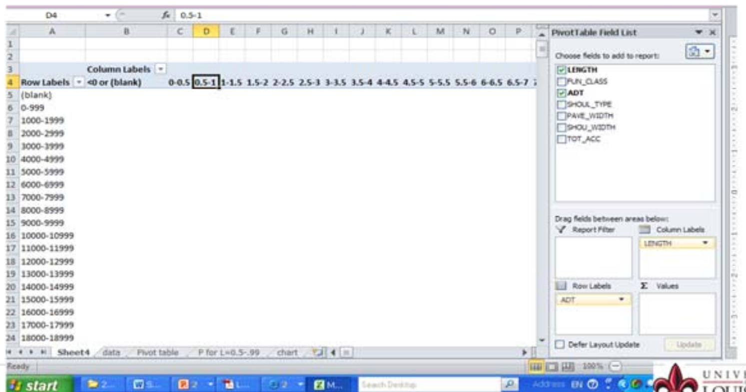
Before starting, be aware

- "Some parts of EDA are ugly, but the real world is ugly, particularly when errors and other aberrant material enter a data set." D.R. Brillinger (2002) writing about the pioneer of EDA, J. W. Tukey.

It is important to point out that there are almost no "perfect" data in real world.

Using Pivot table to explore (visualize) the relationship

- In Excel:
  - Insert Pivot table --Select variable range
  - Define row labels -- Define column labels --place total crashes into Values



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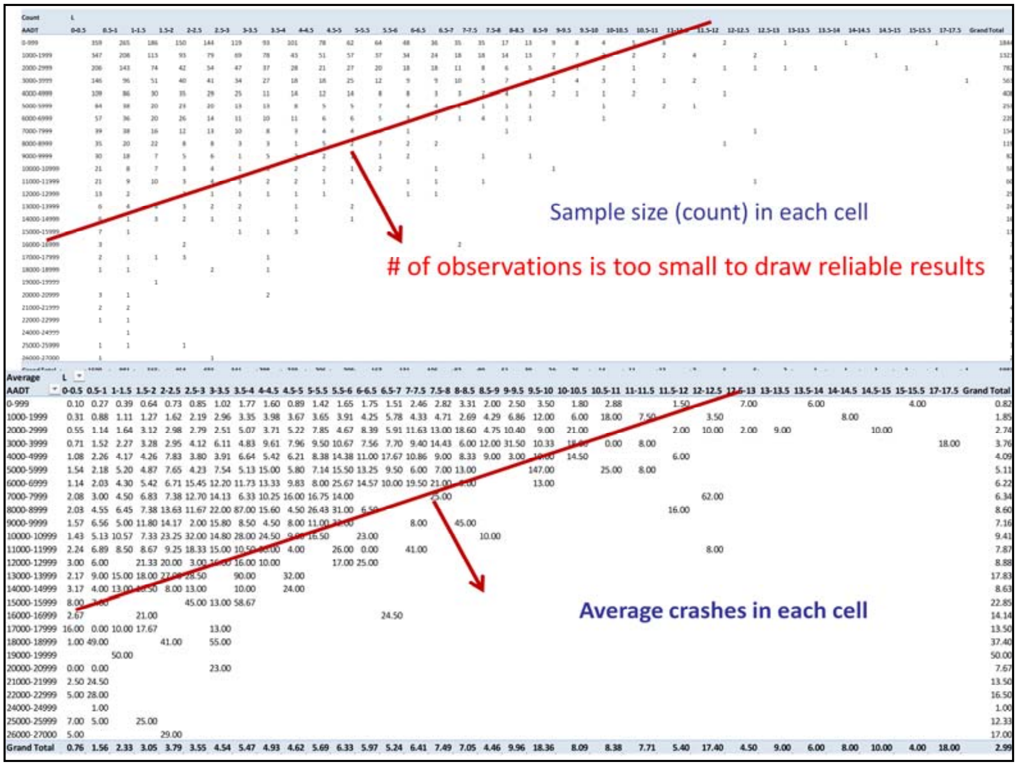
If possible, instructor should spend sometime in class on Pivot Table application.

Results

Count of TOT_ACC	Column Labels																																	
Row Labels	<0 or (blank)	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	7.5-8	8-8.5	8.5-9	9-9.5	9.5-10	10-10.5	10.5-11	11-11.5	11.5-12	12-12.5	12.5-13	13-13.5	13.5-14	14-14.5	14.5-15	15-15.5	17-17.5	Grand Total
(blank)																																		
0-999		359	265	186	150	144	119	93	101	78	62	64	48	36	35	35	17	13	9	8	4	5	8		2		1		1			1		184
1000-1999		347	208	113	93	79	69	78	43	51	57	37	34	24	18	18	14	13	7	7	2	2	2	4		2				1				132
2000-2999		206	143	74	42	54	47	37	28	21	27	20	18	18	11	8	6	5	4	5	2	1			1	1	1	1			1			78
3000-3999		146	96	51	40	41	34	27	18	18	25	12	9	9	10	5	7	2	1	4	3	1	1	2									1	56
4000-4999		109	86	30	35	29	25	11	14	12	14	8	8	3	3	7	4	3	2	1	1	2			1									40
5000-5999		84	38	20	23	20	13	13	8	5	5	7	4	4	2	1	1	1			1		2	1										25
6000-6999		57	36	20	26	14	11	10	11	6	6	5	3	7	1	4	1	1			1													22
7000-7999		39	38	16	12	13	10	8	3	4	4	4	1				1									1								15
8000-8999		35	20	22	8	8	3	3	1	5	2	7	2	2											1									11
9000-9999		30	18	7	5	6	1	5	2	2	1	1	2			1		1																8
10000-10999		21	8	7	3	4	1	5	2	2	1	2		1					1															5
11000-11999		21	9	10	3	4	3	2	2	1	1		1	1		1										1								6
12000-12999		13	2		3	1	1	1	1	1			1	1																				2
13000-13999		6	4	4	3	2	2		1		2																							2
14000-14999		6	1	3	2	1	1		1		1																							1
15000-15999		7	1				1	1	3																									1
16000-16999		3			2										2																			[illegible]
17000-17999		2	1	1	3			1																										[illegible]
18000-18999		1	1			2		1																										[illegible]
19000-19999				1																														[illegible]
20000-20999		3	1					2																										[illegible]
21000-21999		2	2																															[illegible]
22000-22999		1	1																															[illegible]
24000-24999			1																															[illegible]
25000-25999		1	1		1																													[illegible]
26000-27000		1				1																												[illegible]
Grand Total		1500	981	565	454	423	341	298	239	206	208	167	131	106	82	80	51	39	24	25	14	11	13	7	5	5	2	1	1	1	1	1	1	598

Each cell represents total crashes in that population group defined by AADT (presented by each row) and segment length (by column). Applying Excel tool Pivot Table, the average, standard deviation and count can be displayed.



Discuss the relationship between simple size and reliability of average crashes in each cell.

Average	L														
AADT	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5
0-999	0.10	0.27	0.39	0.64	0.73	0.85	1.02	1.77	1.60	0.89	1.42	1.65	1.75	1.51	2.46
1000-1999	0.31	0.88	1.11	1.27	1.62	2.19	2.96	3.35	3.98	3.67	3.65	3.91	4.25	5.78	4.33
2000-2999	0.55	1.14	1.64	3.12	2.98	2.79	2.51	5.07	3.71	5.22	7.85	4.67	8.39	5.91	11.63
3000-3999	0.71	1.52	2.27	3.28	2.95	4.12	6.11	4.83	9.61	7.96	9.50	10.67	7.56	7.70	9.40
4000-4999	1.08	2.26	4.17	4.26	7.83	3.80	3.91	6.64	5.42	6.21	8.38	14.38	11.00	17.67	10.86
5000-5999	1.54	2.18	5.20	4.87	7.65	4.23	7.54	5.13	15.00	5.80	7.14	15.50	13.25	9.50	6.00
6000-6999	1.14	2.03	4.30	5.42	6.71	15.45	12.20	11.73	13.33	9.83	8.00	25.67	14.57	10.00	19.50
7000-7999	2.08	3.00	4.50	6.83	7.38	12.70	14.13	6.33	10.25	16.00	16.75	14.00			
8000-8999	2.03	4.55	6.45	7.38	13.63	11.67	22.00	87.00	15.60	4.50	26.43	31.00	6.50		
9000-9999	1.57	6.56	5.00	11.80	14.17	2.00	15.80	8.50	4.50	8.00	11.00	32.00			8.00
10000-10999	1.43	5.13	10.57	7.33	23.25	32.00	14.80	28.00	24.50	9.00	16.50		23.00		
11000-11999	2.24	6.89	8.50	8.67	9.25	18.33	15.00	10.50	30.00	4.00		26.00	0.00		41.00
12000-12999	3.00	6.00		21.33	20.00	3.00	16.00	16.00	10.00			17.00	25.00		

Count	L														
AADT	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5
0-999	359	265	186	150	144	119	93	101	78	62	64	48	36	35	35
1000-1999	347	208	113	93	79	69	78	43	51	57	37	34	24	18	18
2000-2999	206	143	74	42	54	47	37	28	21	27	20	18	18	11	8
3000-3999	146	96	51	40	41	34	27	18	18	25	12	9	9	10	5
4000-4999	109	86	30	35	29	25	11	14	12	14	8	8	3	3	7
5000-5999	84	38	20	23	20	13	13	8	5	5	7	4	4	2	1
6000-6999	57	36	20	26	14	11	10	11	6	6	5	3	7	1	4
7000-7999	39	38	16	12	13	10	8	3	4	4	4	1			
8000-8999	35	20	22	8	8	3	3	1	5	2	7	2	2		
9000-9999	30	18	7	5	6	1	5	2	2	1	1	2			1
10000-10999	21	8	7	3	4	1	5	2	2	1	2		1		
11000-11999	21	9	10	3	4	3	2	2	1	1		1	1		1
12000-12999	13	2		3	1	1	1	1	1			1	1		

Same table but enlarged

7.5-8	8-8.5	8.5-9	9-9.5	9.5-10	10-10.5	10.5-11	11-11.5	11.5-12	12-12.5	12.5-13	13-13.5	13.5-14	14-14.5	14.5-15	15-15.5	17-17.5	Grand Total
2.82	3.31	2.00	2.50	3.50	1.80	2.88		1.50		7.00		6.00			4.00		0.82
4.71	2.69	4.29	6.86	12.00	6.00	18.00	7.50		3.50				8.00				1.85
13.00	18.60	4.75	10.40	9.00	21.00			2.00	10.00	2.00	9.00			10.00			2.74
14.43	6.00	12.00	31.50	10.33	18.00	0.00	8.00									18.00	3.76
9.00	8.33	9.00	3.00	10.00	14.50			6.00									4.09
7.00	13.00			147.00		25.00	8.00										5.11
21.00	9.00			13.00													6.22
25.00									62.00								6.34
								16.00									8.60
	45.00																7.16
		10.00															9.41
									8.00								7.87
																	8.88

7.5-8	8-8.5	8.5-9	9-9.5	9.5-10	10-10.5	10.5-11	11-11.5	11.5-12	12-12.5	12.5-13	13-13.5	13.5-14	14-14.5	14.5-15	15-15.5	17-17.5	Grand Total
17	13	9	8	4	5	8		2		1		1			1		1844
14	13	7	7	2	2	2	4		2				1				1323
6	5	4	5	2	1			1	1	1	1			1			782
7	2	1	4	3	1	1	2									1	563
4	3	2	1	1	2			1									408
1	1			1		2	1										253
1	1			1													220
1									1								154
								1									119
	1																82
		1															58

Insufficient observations with longer segment length

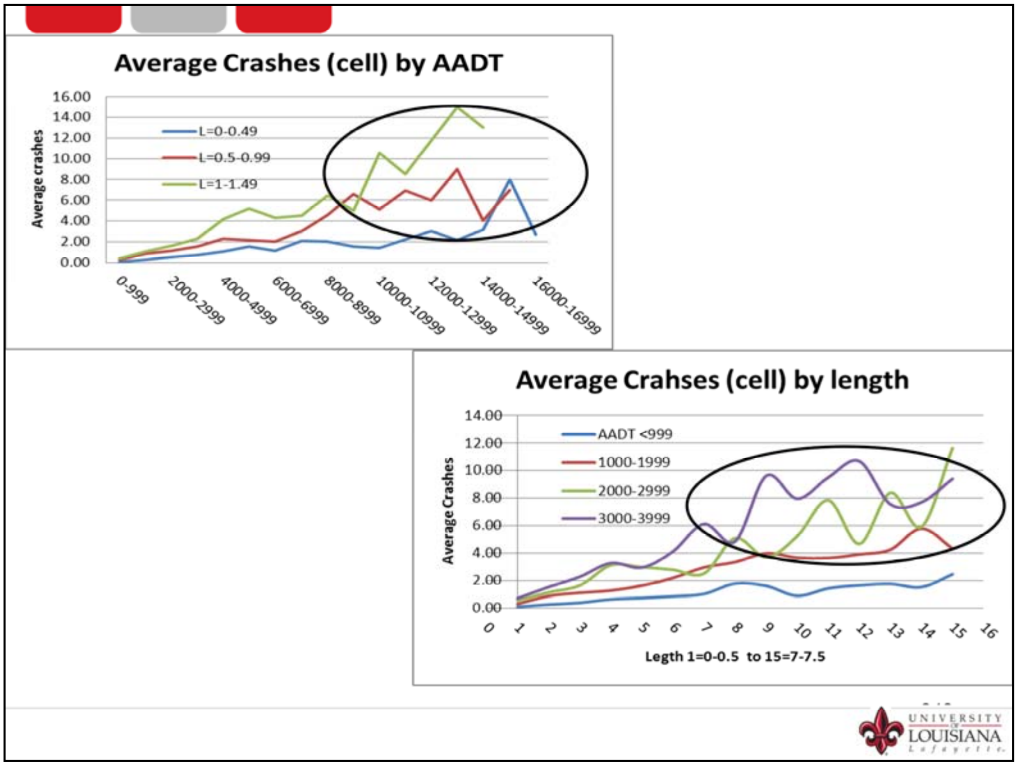
Stress the problem of smaller sample size with segment of longer length.

13000-13999	2.17	9.00	15.00	18.00	27.00	28.50		90.00		32.00				
14000-14999	3.17	4.00	13.00	10.50	8.00	13.00		10.00		24.00				
15000-15999	8.00	7.00				45.00	13.00	58.67						
16000-16999	2.67			21.00										24.50
17000-17999	16.00	0.00	10.00	17.67			13.00							
18000-18999	1.00	49.00			41.00		55.00							
19000-19999			50.00											
20000-20999	0.00	0.00					23.00							
21000-21999	2.50	24.50												
22000-22999	5.00	28.00												
24000-24999		1.00												
25000-25999	7.00	5.00		25.00										
26000-27000	5.00				29.00									
Grand Total	**0.76**	**1.56**	**2.33**	**3.05**	**3.79**	**3.55**	**4.54**	**5.47**	**4.93**	**4.62**	**5.69**	**6.33**	**5.97**	**5.24**

13000-13999	6	4	4	3	2	2		1		2				
14000-14999	6	1	3	2	1	1		1		1				
15000-15999	7	1				1	1	3						
16000-16999	3			2										2
17000-17999	2	1	1	3			1							
18000-18999	1	1			2		1							
19000-19999			1											
20000-20999	3	1					2							
21000-21999	2	2												
22000-22999	1	1												
24000-24999		1												
25000-25999	1	1		1										
26000-27000	1				1									
Grand Total	**1500**	**981**	**565**	**454**	**423**	**341**	**298**	**239**	**206**	**208**	**167**	**131**	**106**	**82**

Insufficient observations with bigger AADT

- Similarly, the problem of smaller sample size with higher AADT

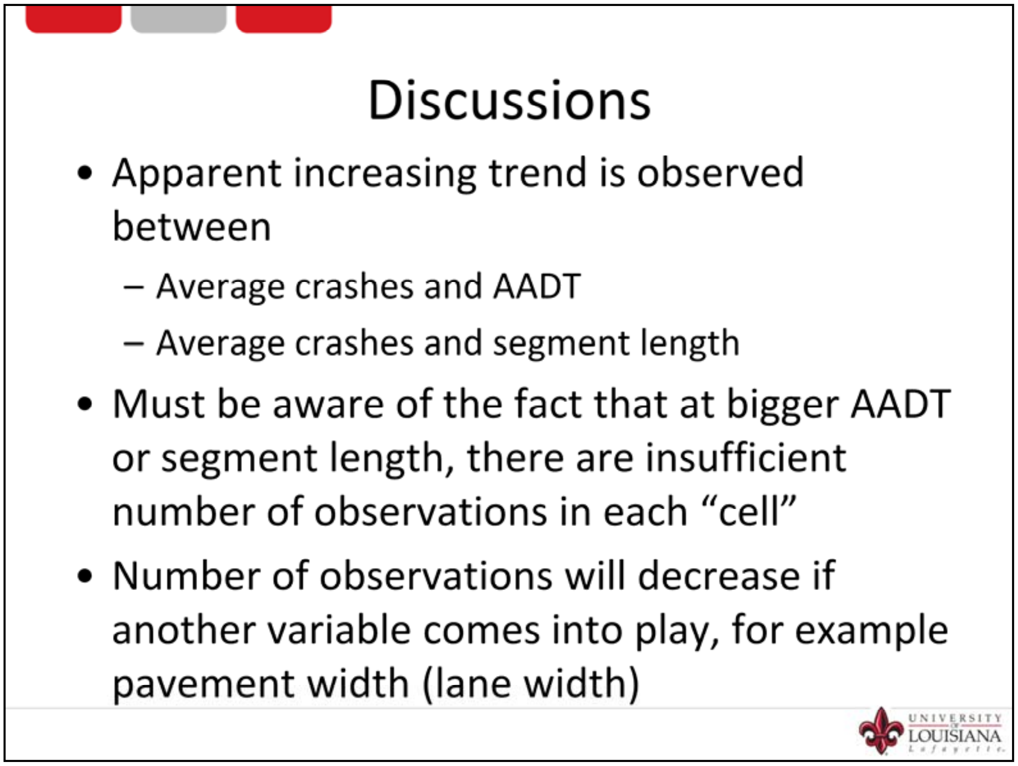


Discuss the charts:

1.Is there a trend?

2.Why curves are smoother when value of variable are small?

3.Why curves are irregular when values of variables are bigger?



- Discussion summary

Average Crashes for L=1.0-1.499 miles (AADT and Pavement Width)

Row Labels	10	16	18	19	20	21	22	24	25	26	28	30	34	36	Grand Total
0-999	0	0.00	0.18	0.00	0.18	0.00	0.34	0.61			2.00				0.27
1000-1999		0.67	0.92		0.63		1.02	1.16		0.00	2.00				0.88
2000-2999			0.50		1.12		1.06	1.27	1.00	0.00	0.00				1.14
3000-3999			0.00		1.50		1.00	1.98		3.00	0.00				1.52
4000-4999			2.00		1.89		5.92	1.53	2.00	1.00			4.00		2.26
5000-5999			3.00		4.00		4.00	1.59		5.00		0.00			2.18
6000-6999			0.00		5.00		3.50	1.52		7.00				1.00	2.03
7000-7999			1.00		3.50		2.75	3.04			4.00				3.00
8000-8999					7.50			4.22							4.55
9000-9999					15.00		12.00	4.79							6.56
10000-10999					0.00			5.86							5.13
11000-11999								7.38		3.00					6.89
12000-12999								6.00							6.00
13000-13999								9.00							9.00
14000-14999								4.00							4.00
15000-15999					7.00										7.00
17000-17999								0.00							0.00
18000-18999								49.00							49.00
20000-20999								0.00							0.00
21000-21999							44.00	5.00							24.50
22000-22999					28.00										28.00
24000-24999								1.00							1.00
25000-26000					5.00										5.00
Grand Total	0	0.29	0.50	0.00	0.88	0.00	1.86	2.15	1.50	1.82	1.67	0.00	4.00	1.00	1.56

Further analysis is performed by examining the impact of pavement width. Here segment length is fixed at 1.0 to 1.499 miles. It is well known that safety is related to lane width in rural 2-lane highways. Do you see that in this table?

It seems we only see that when AADT is higher than 5,000.

of counts for L=1.0-1.499 miles (AADT and Pavement Width)

Row Labels	10	16	18	19	20	21	22	24	25	26	28	30	34	36	Grand Total
0-999	1	4	22	2	155	1	41	38			1				265
1000-1999		3	13		87		44	55		4	2				208
2000-2999			4		41		32	63	1	1	1				143
3000-3999			5		18		25	46		1	1				96
4000-4999			1		9		13	59	1	2			1		86
5000-5999			1		5		3	27		1		1			38
6000-6999			1		2		4	27		1				1	36
7000-7999			1		4		8	24			1				38
8000-8999					2			18							20
9000-9999					1		3	14							18
10000-10999					1			7							8
11000-11999								8		1					9
12000-12999								2							2
13000-13999								4							4
14000-14999								1							1
15000-15999					1										1
17000-17999								1							1
18000-18999								1							1
20000-20999								1							1
21000-21999							1	1							2
22000-22999					1										1
24000-24999								1							1
25000-26000					1										1
Grand Total	**1**	**7**	**48**	**2**	**328**	**1**	**174**	**398**	**2**	**11**	**6**	**1**	**1**	**1**	**981**

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But sample sizes are small.

Considering # of observations

Row Labels	10	16	18	19	20	21	22	24	25	26	28	30	34	36	Grand Total
0-999	0	0.00	0.18	0.00	0.18	0.00	0.34	0.61			2.00				0.27
1000-1999		0.67	0.92		0.63		1.02	1.16		0.00	2.00				0.88
2000-2999			0.50		1.12		1.06	1.27	1.00	0.00	0.00				1.14
3000-3999			0.00		1.50		1.00	1.98		3.00	0.00				1.52
4000-4999			2.00		1.89		5.92	1.53	2.00	1.00			4.00		2.26
5000-5999			3.00		4.00		4.00	1.59		5.00		0.00			2.18
6000-6999			0.00		5.00		3.50	1.52		7.00				1.00	2.03
7000-7999			1.00		3.50		2.75	3.04			4.00				3.00
8000-8999					7.50			4.22							4.55
9000-9999					15.00		12.00	4.79							6.56
10000-10999					0.00			5.86							5.13
11000-11999								7.38		3.00					6.89
12000-12999								6.00							6.00
13000-13999								9.00							9.00
14000-14999								4.00							4.00
15000-15999					7.00										7.00
17000-17999								0.00							0.00
18000-18999								49.00							49.00
20000-20999								0.00							0.00
21000-21999							44.00	5.00							24.50
22000-22999					28.00										28.00
24000-24999								1.00							1.00
25000-26000					5.00										5.00
Grand Total	0	0.29	0.50	0.00	0.88	0.00	1.86	2.15	1.50	1.82	1.67	0.00	4.00	1.00	1.56

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Again, What does this table reveal?

1. Average crashes increase as AADT increases (already known from the first Pivot table)
2. Average crashes decrease with lane width increasing to 12 ft. At high AADT level.

More discussions

- Impact of lane width (pavement width) does not match intuition (comparing average crashes at w=18, 20, and 24 feet)
- It is possible the positive impact of pavement width occurring at high AADT level but no sufficient data there to verify
- It is possible there are other variables affecting the results such as horizontal curves
- Results confirm one fact: crashes increase as AADT increases.

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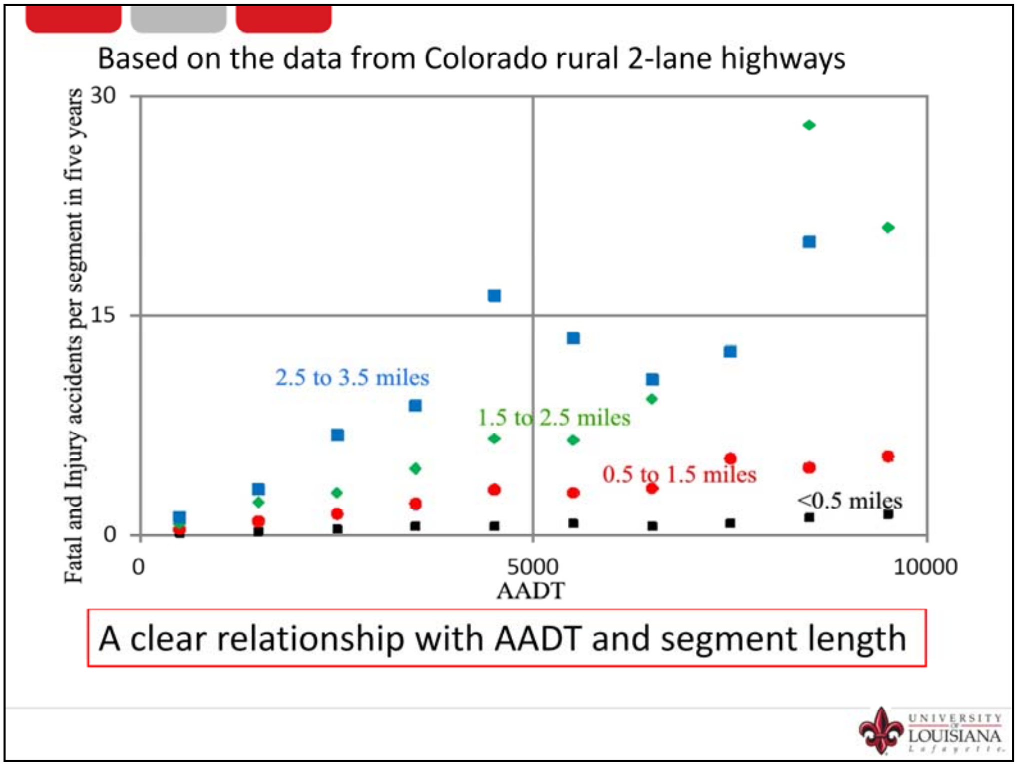
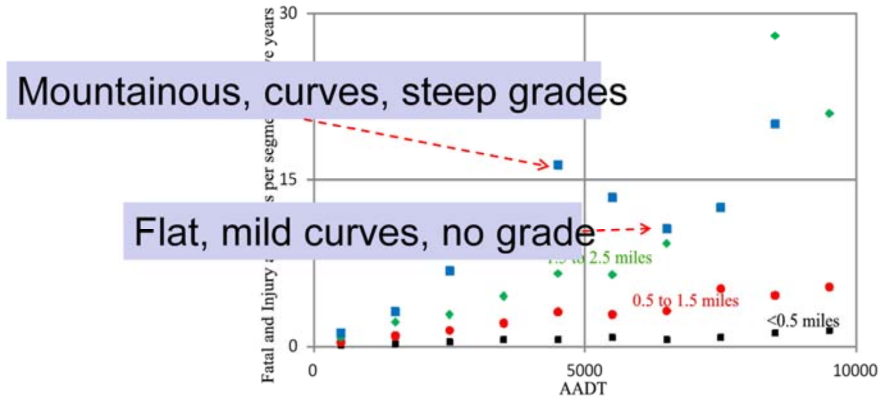


Another example showing AADT vs. average crashes per segment at three segment length.

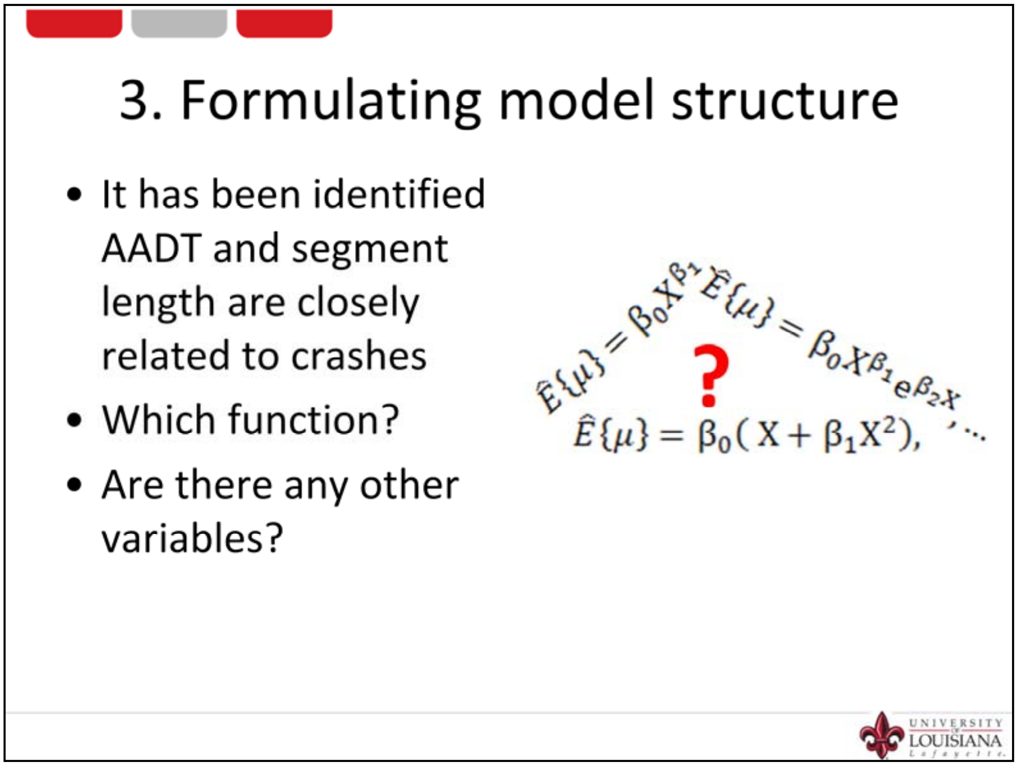
Source: Dr. Hauer's 2013 SPF Workshop in Baton Rouge, LA

Again, the average fluctuation may caused by:

1. Randomness of crash counts;
2. Many samples have few segments;
3. Differences in unaccounted-for attributes.



Source: Dr. Hauer’s 2013 SPF Workshop in Baton Rouge, LA



After EDA, it is time to formulate model structure. Two key questions:

1. Model functional form
2. Number of variables

Possible Functions

Linear	$Y=\beta_0+\beta_1X_1+\beta_2X_2$
Power	X^{β}
Polynomial	$L+\beta L^2$
Hoerl	$X^{\beta_1}e^{\beta_2 X}$
Others	$e^{\sum \beta_i X_i}$
Mixtures	$\hat{E}\{\mu\}=\beta_0 L^{\beta_1} AADT^{\beta_2} e^{\beta_3 AADT}$

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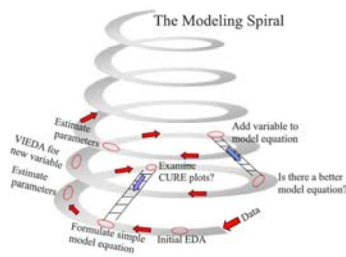
Determining what function hides behind the noisy data is key to getting good estimates of $E\{\mu\}$ and $\sigma\{\mu\}$.

Based on Dr. Ezra Hauer

- The tools for finding the right function form are not well developed.
- It works like spiral with modeling steps 4 and 5.



There is only general guidance on the selection of functional form. Developing appropriate functional form requires lots of trial and error.

4. Parameter Estimation

- The model parameters depend on the selection of objective functions

	Method
Conventional	Ordinary Least Square
	Maximum Likelihood
Unconventional	Absolute Differences
	χ^2
	Total Absolute Bias

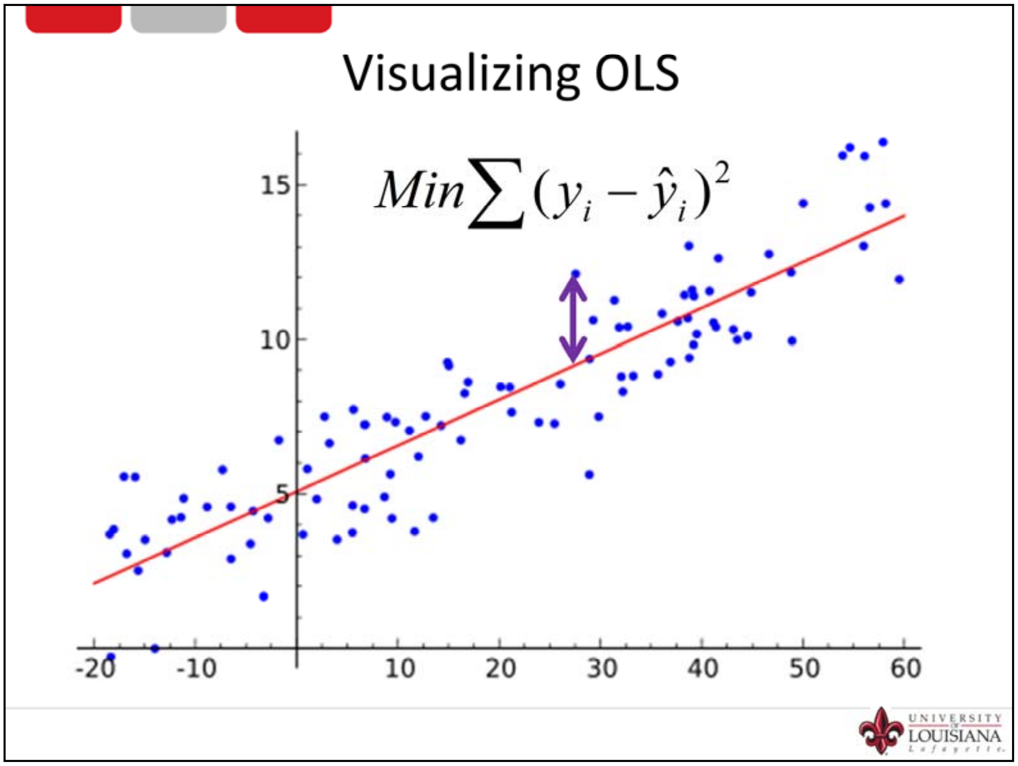
As most engineering students learned in statistics, there are several methods for parameter estimation. Different methods yield different results.

Ordinary Least Squares (OLS)

In statistics, **ordinary least squares (OLS)** or **linear least squares** is a method for estimating the unknown parameters in a linear regression model. (can also be used in non-linear models by transforming a nonlinear form into a linear one) This method minimizes the sum of squared vertical distances between the observed responses in the dataset and the responses predicted by the linear approximation.

From Wikipedia

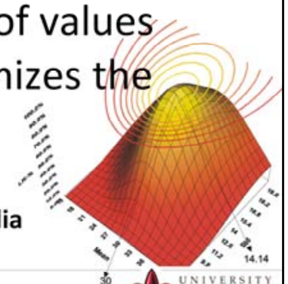
OLS is one of the most common methods used in parameter estimation.



Where x-axes is independent variable and Y-axes presents the dependent variable. Each dot presents a observed data and red line presents the model.

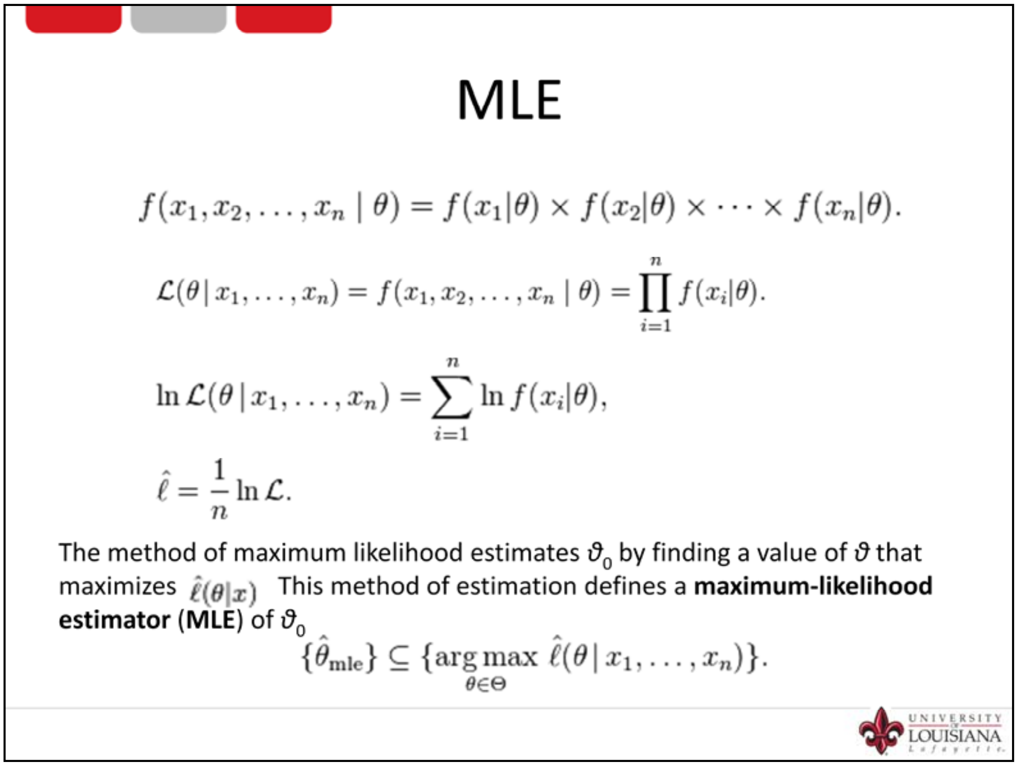
Maximum-Likelihood Estimation (MLE)

- In statistics, **maximum-likelihood estimation** (**MLE**) is a method of estimating the parameters of a statistical model.
- In general, for a fixed set of data and underlying statistical model, the method of maximum likelihood selects the set of values of the model parameters that maximizes the likelihood function.



From Wikipedia

MLE has a totally different objective from OLS.

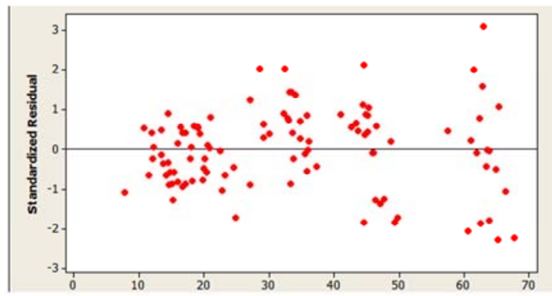


MLE can be expressed mathematically as in the slide.

4. Model evaluation (fitness of a model)

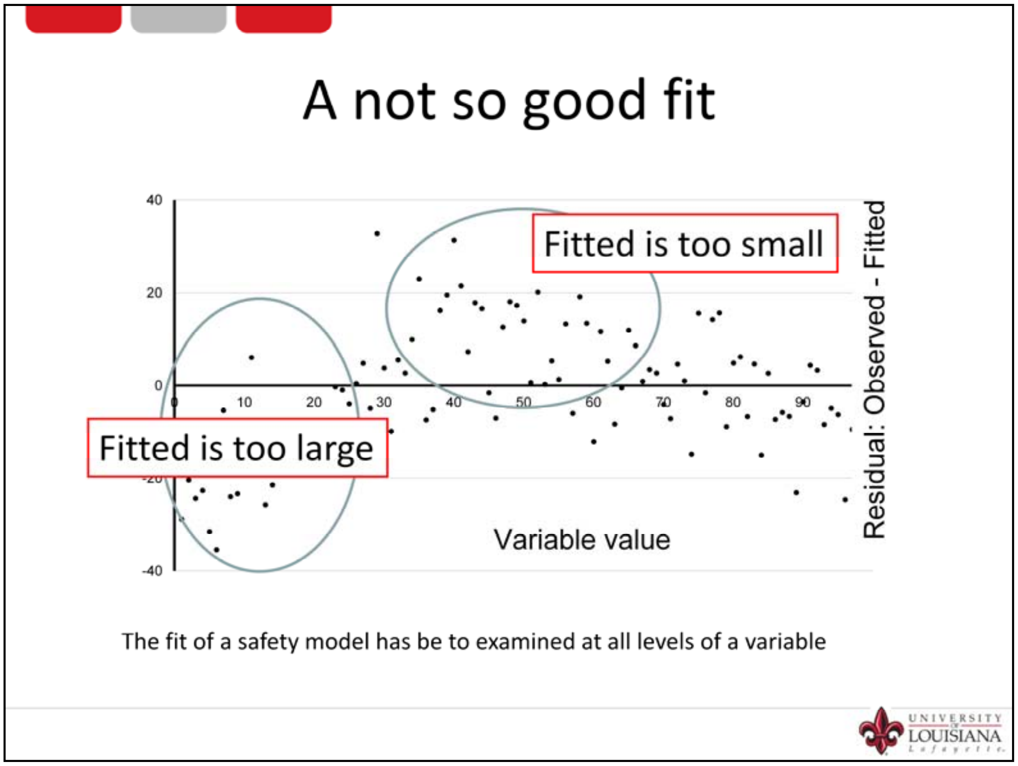
- The fit of a model is judged by its residuals.
- A fit is thought good only if the residuals are closely packed around 0 <u>everywhere</u>

Residual=observed – modeled (Fitted)



Does the developed model work well? This question must be answer by model evaluation process. Residual is a good measure of the model and can be visualized in a chart where x-axes presents independent variable and Y-axes is Res (observed minus predicted/fitted)

Source: Dr. Hauer’s 2013 SPF Workshop in Baton Rouge, LA



This residual plot may come from a developed model that has a good overall fit. By examining its distribution over one variable, it is clear that the model predictability varies depending on the value of independent variable. In safety model application, it may not be not acceptable.

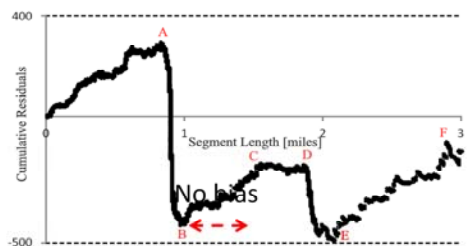
Discuss why it is not acceptable in safety model application.

Chart comes from Dr. Hauer’s 2013 SPF Workshop in Baton Rouge, LA

Cumulated residual Plot (CURE)

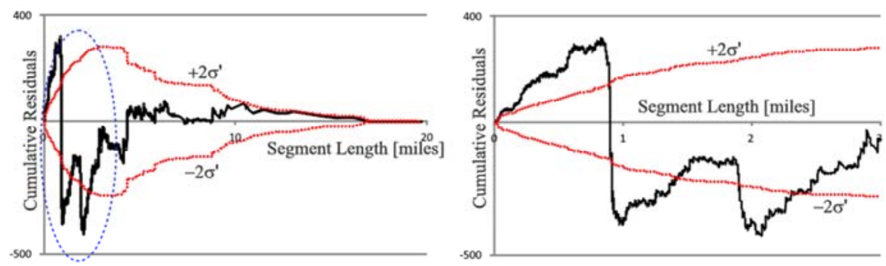
- CURE can give more information on the model fitness
- What should a good CURE plot look like?
  - Should not have long up or down runs
  - Should not have vertical drops
  - Should meander around the horizontal axis

What about this CURE?



In addition to residue plot, the CURE plot is also very helpful in model evaluation.
Source: Dr. Hauer’s 2013 SPF Workshop in Baton Rouge, LA

Rule of thumb: 95% within ±2s’



Having a perfect CURE is hard. We need some kind of yardstick to evaluate CURE.

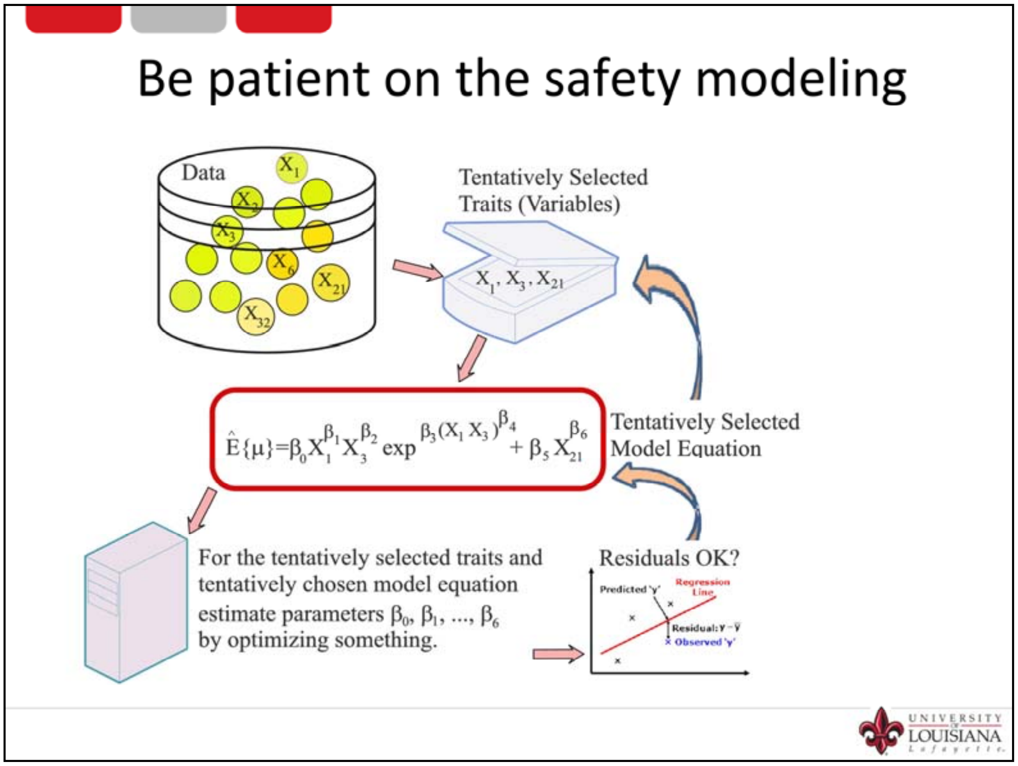
Source: Dr. Hauer’s 2013 SPF Workshop in Baton Rouge, LA

Again, based On Dr. Ezra Hauer

- “For the purposes for which SPFs are developed the ‘overall goodness of fit’ is of little interest. We want SPFs to produce good estimates of E{μ} and σ{μ} for all variable values of practical interest. An SPF that overestimates E{μ} for one range of variables and underestimates it elsewhere may fit well overall but is ‘biased everywhere’ and, as such, of little practical use.”
- **An SPF model is practically useful to the extent that it is nearly unbiased everywhere.**

Continuing the discussion on why overall fit is not good enough for safety model application.

For example, you are doing network screening by using EB method.



SPF development is not predefined sequence of steps; it is a gradual progress towards a satisfactory result consisting of steps and missteps.

Source: Dr. Hauer’s 2013 SPF Workshop in Baton Rouge, LA

A Class Exercise

- With Colorado rural 2-lane data from the 2013 SPF workshop
  - Solver with one variable (AADT)
    - Minimize SSD
    - Maximize Likelihood (Poisson)
  - Residual and CURE plots

Source: Dr. Hauer’s 2013 SPF Workshop in Baton Rouge, LA

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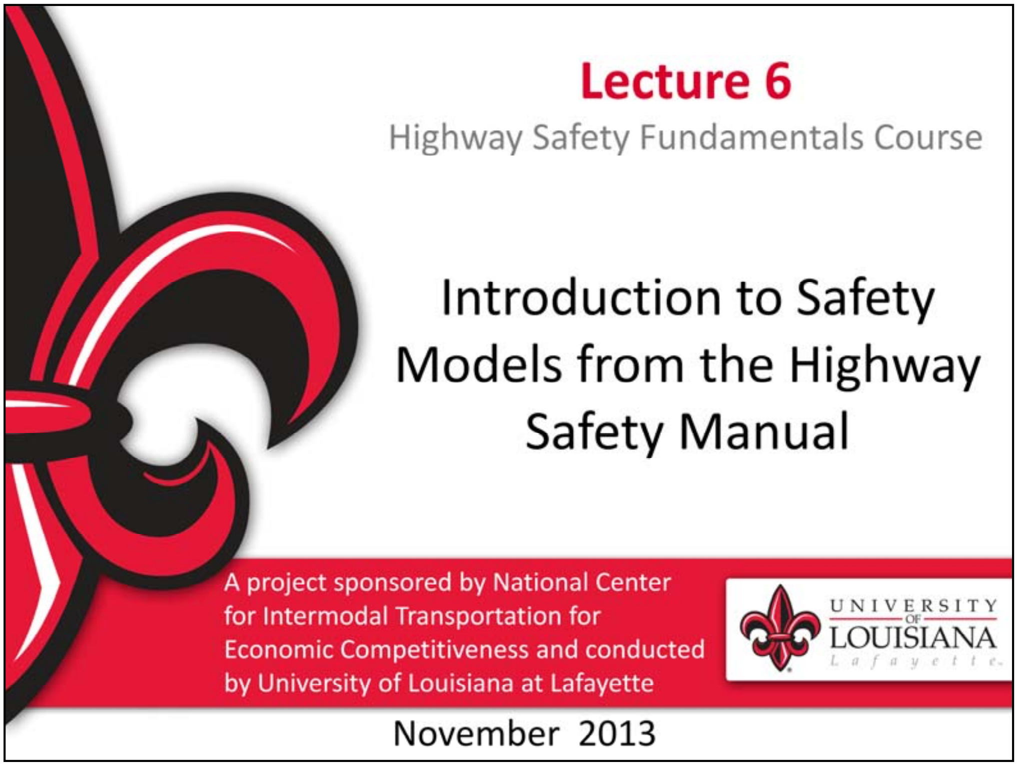
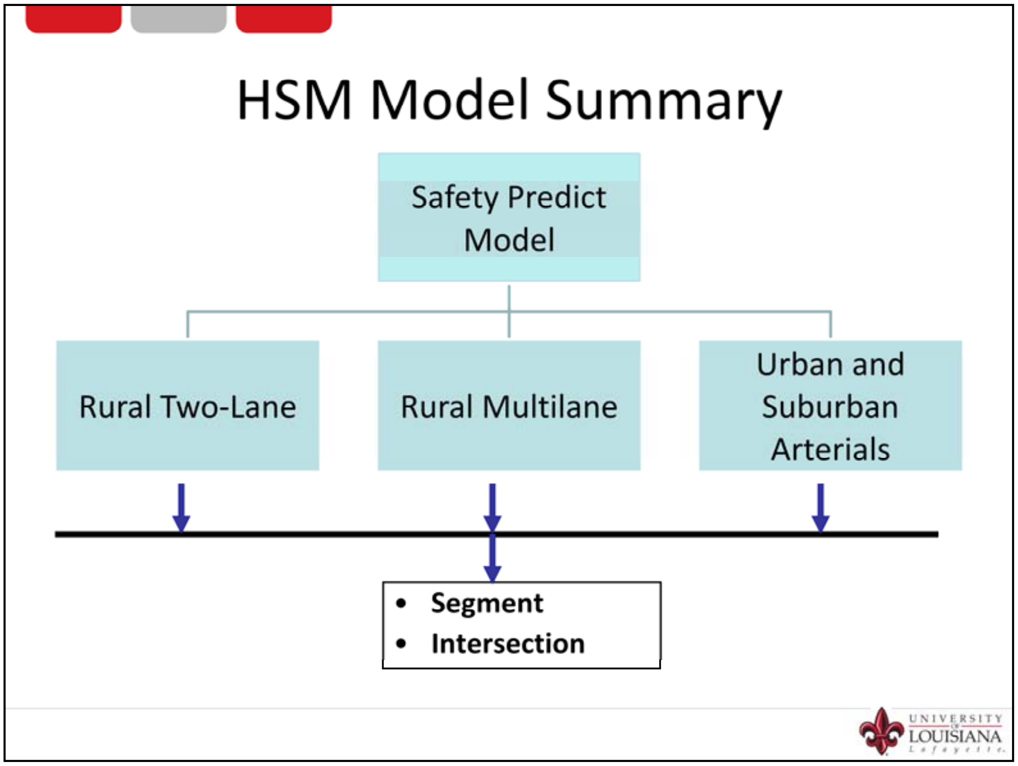


The objective of this lecture is to let student be familiar with the safety models for the three types of highways from the first edition of the HSM.

Safety Models

- **Introduction**
- Rural 2-lane morels
- Rural Multilane Model
- Urban and Suburban Arterial Model

Three chapters in the first edition of the HSM deal with safety models for three types of highways.



Also by segment and intersection because these two roadway facilities perform very differently in safety.

Basic Elements in Safety Predictive Model

1. SPF (on base condition)
2. Crash Modification Factor (CMF)
3. Calibration parameter
4. EB weighting factor

For consistence, all three types of highways (including two facilities type) have similar model structure. There are four elements in each model.

General functional format

$$\boxed{N_{predicted} = N_{SPFx} \times \prod CMF_i \times C}$$

Where,

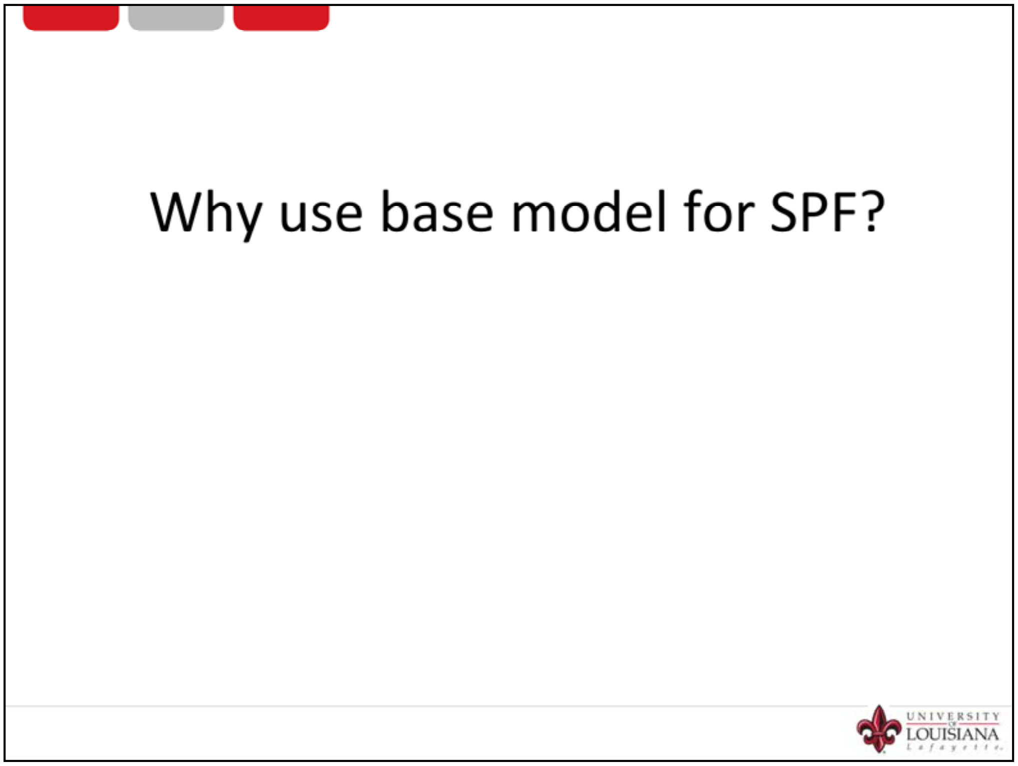
$N_{predicted}$= predictive model estimate of crash frequency for a specific year on site type x (crashes/year);

$N_{SPF\ x}$= predicted average crash frequency determined for base conditions with the Safety Performance Function (SPF) representing site type x (crashes/year);

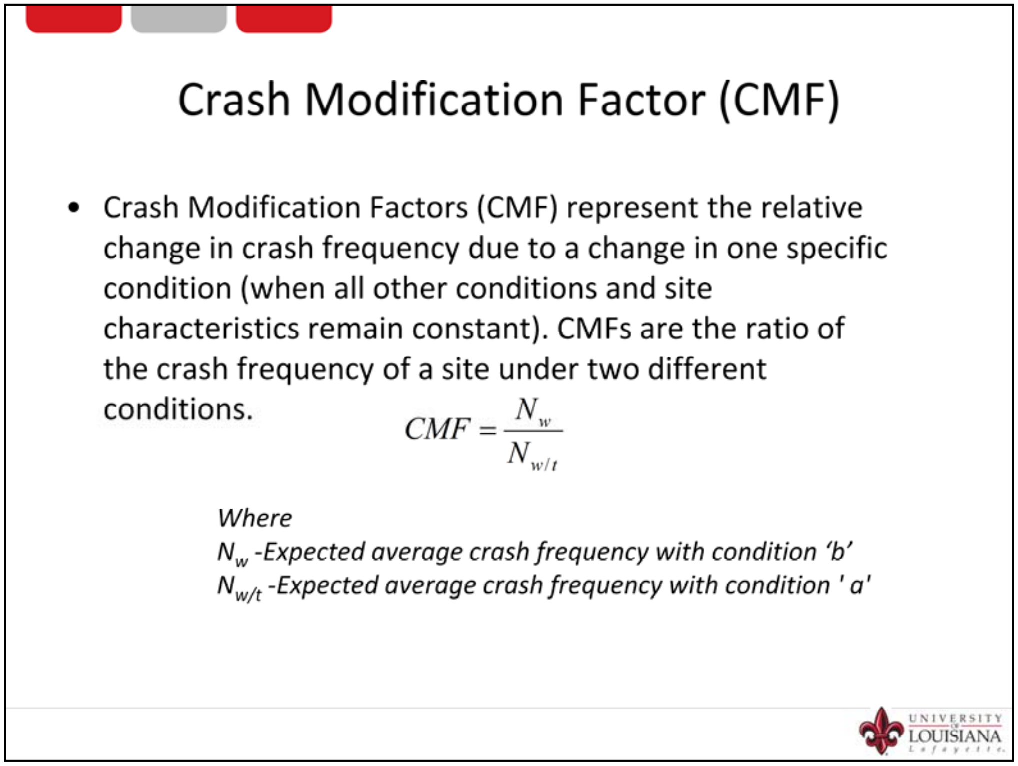
CMF_x = Crash Modification Factors specific to site type x;

C_x = Calibration Factor to adjust for local conditions for site type

First three elements include SPF, Crash Modification Factors (CMF) and a calibration factor.



Base models are useful in predicting overall accident frequency, but their coefficients cannot necessarily be relied upon to represent the incremental effects of individual geometric design and traffic control features; therefore, the base models are not sufficient, by themselves, to make reliable predictions of safety performance of a highway facility (segment or intersection) because they are not necessarily sensitive to all of the geometric design and traffic control features of interest.



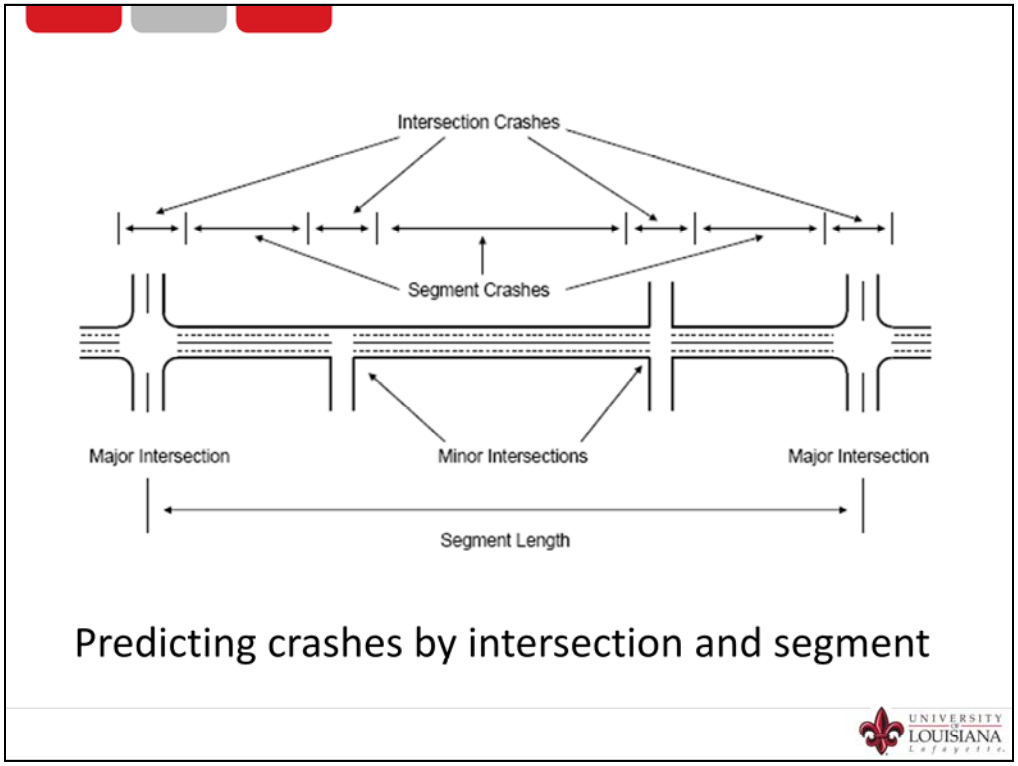
Therefore, a CMF may serve as an estimate of the effect of a particular geometric design or traffic control feature or the effectiveness of a particular treatment or condition.

Calibration Factor

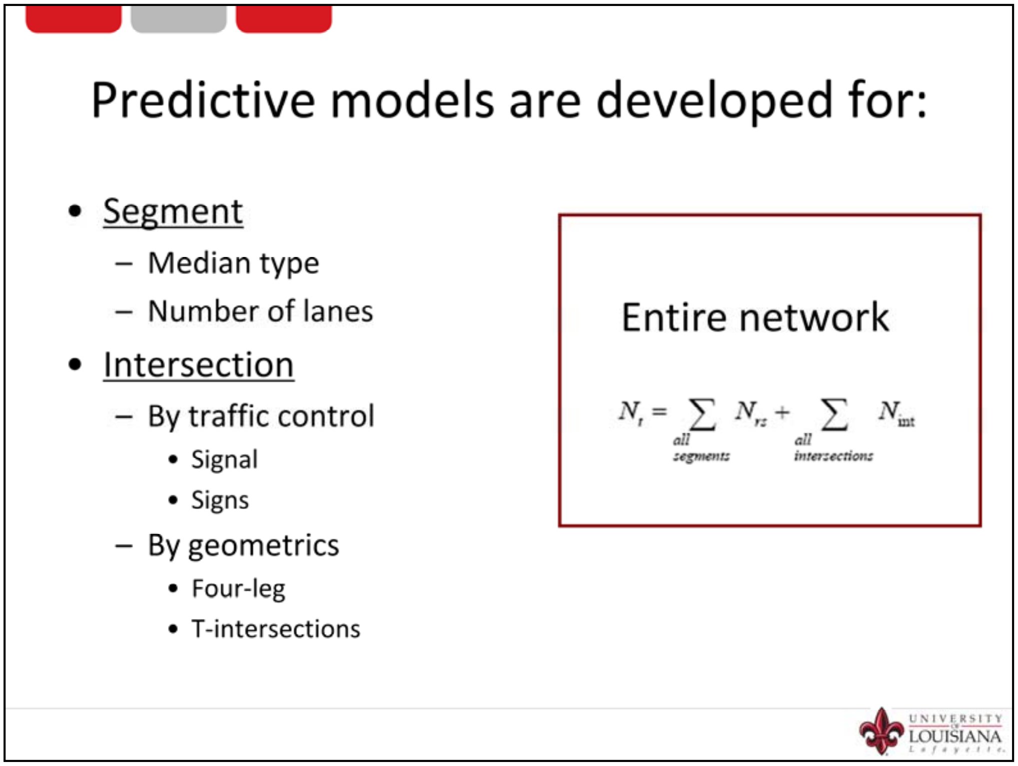
A calibration factor (C) is used to account for differences between the jurisdictions for which the models were developed and the jurisdiction for which the predictive method is applied.

Differences in:

- Crash reporting thresholds, and crash reporting system procedures
- Weather condition
- Driver behavior



As introduced previously, there are two basic analysis elements for safety mode. This chart illustrates the classification of segment and intersection.



Due to the difference in cross-section design, the segment can be further grouped by median type and number of lanes. And intersection can be further grouped by type of traffic control and layout.

Discuss why further grouping is important.

Application of Empirical Bayes (EB) Method

- The EB procedure should be applied whenever observed crash history data are available

$$N_{\exp} = w \times N_{pre} + (1-w) \times N_{ob.}$$

$$w = \frac{1}{1 + k \times \sum_{years} N_{pre}}$$

Where,
N_{exp} = estimate of expected average crash frequency for the study period
N_{pre}= predictive model estimate of predicted average crash frequency for the study period;
$N_{observed}$ = observed crash frequency at the site over the study period;
w = weighted adjustment to be placed on the SPF prediction;
k = overdispersion parameter.

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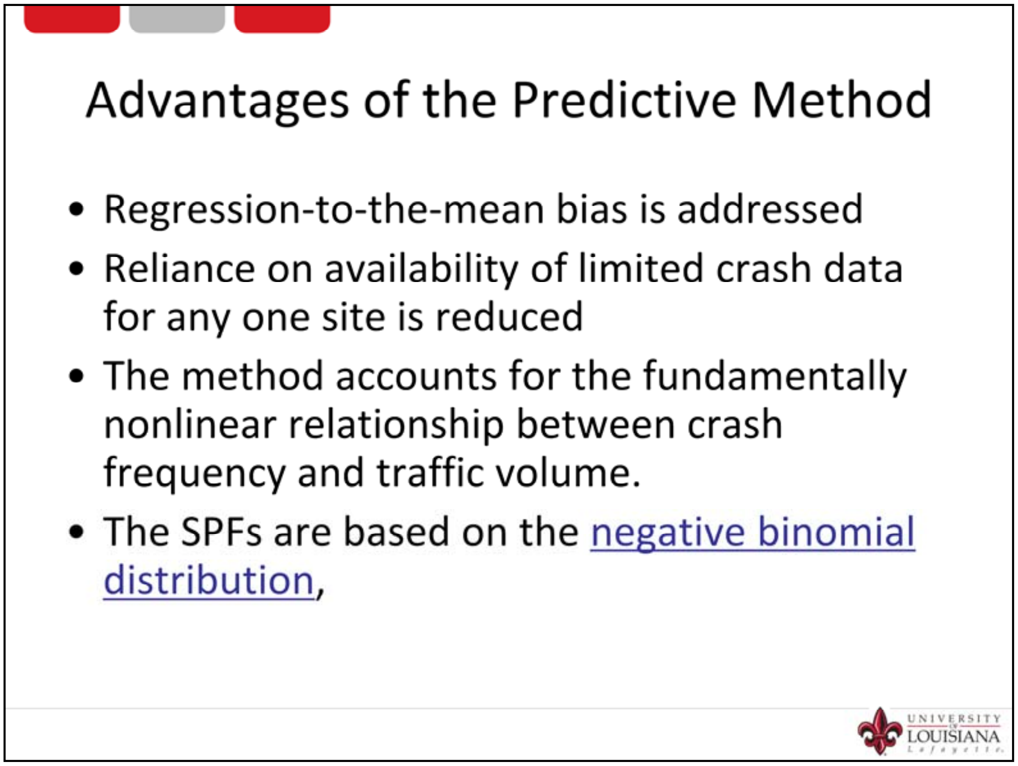
The EB application model is straightforward—considering location special safety performance. The key is weighting factor, W.



Regression-to-the-mean bias is addressed as the method concentrates on long-term expected average crash frequency rather than short-term observed crash frequency.

Reliance on availability of limited crash data for any one site is reduced by incorporating predictive relationships based on data from many similar sites.

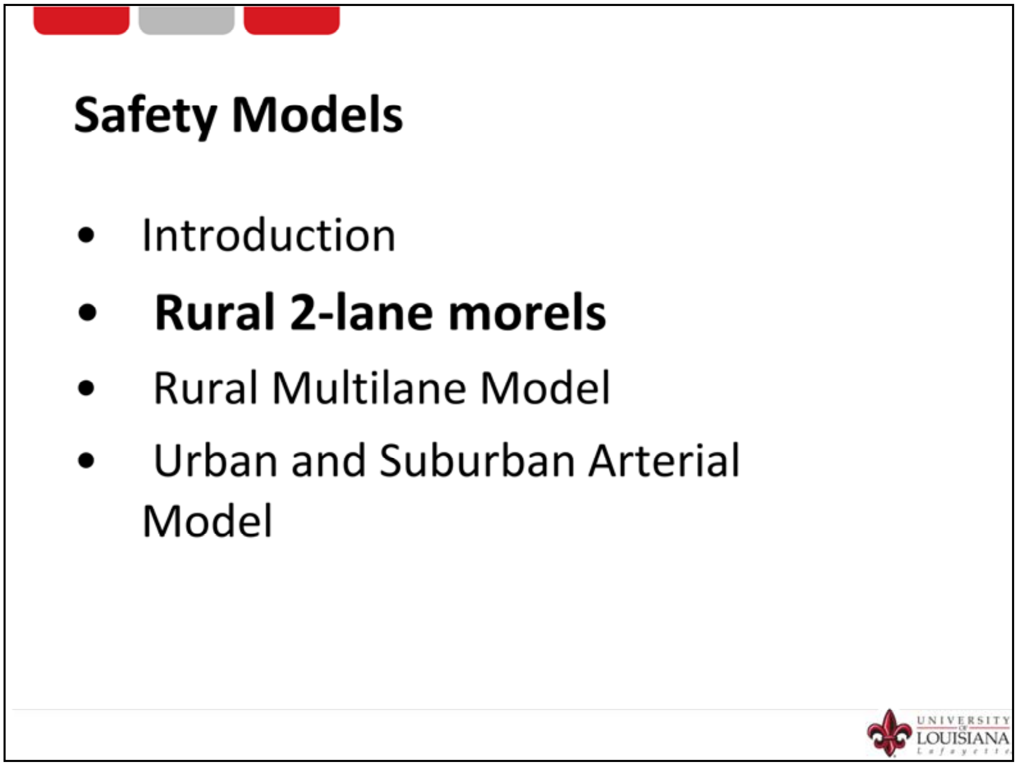
The method accounts for the fundamentally nonlinear relationship between crash frequency and traffic volume.

The SPFs are based on the negative binomial distribution, which is better suited for modeling the high natural variability of crash data than traditional modeling techniques, which are based on the normal distribution.

Limitation

- The model incorporates the effects on safety of many, but not all, geometric and traffic control features of potential interest.
- The model generally treats the effects of individual geometric design and traffic control features as independent of one another and ignores potential interactions between them.
- Enforcement and education actions are basically not considered

Only those geometric features whose relationship to safety is well understood are included in the procedure. It is likely that such interactions exist, and ideally, they should be accounted for in the safety prediction procedure; however, such interactions are poorly understood and difficult to quantify.



Three chapters in the first edition of HSM deal with safety models for three types of highways.

- Stop sign controlled
- Signalized

Introduce the overall models.

- ST as sign controlled
- SG as signalized
- The number indicated the intersection type, four leg or T intersection

Analysis Unit

- Segment with uniform attributes
- Intersection
  - Three-leg intersections with minor-road stop control (3ST)
  - Four-leg intersections with minor-road stop control (4ST)
  - Four-leg signalized intersections (4SG)

Each segment must have uniform attributes, such as same lane width, shoulder width, and etc.

Segment base model (SPF)

$$N_{spf} = AADT \times L \times 365 \times 10^{-6} \times e^{-0.312}$$

Where,
N_{spf} = predicted total crash frequency for roadway segment base conditions;
AADT = average annual daily traffic volume (vehicles per day);
L = length of roadway segment (miles)

Note that only two variables are in base model.

Segment base condition

• Lane width (LW)	12 feet
• Shoulder width (SW)	6 feet
• Shoulder type	Paved
• Roadside hazard rating (RHR)	3
• Driveway density (DD)	5 driveways per mile
• Horizontal curvature	None
• Vertical curvature	None
• Centerline rumble strips	None
• Passing lanes	None
• Two-way left-turn lanes	None
• Lighting	None
• Automated speed enforcement	None
• Grade Level	0%

Stress that other variables in base model are considered in "base condition" defined here.

A 0% grade is not allowed by most states because of drainage need.

The SPF uses 0% as a numerical base condition that must always be modified based on the actual grade.

Crash Modification Factor for lane width

Lane Width	AADT (veh/day)		
	< 400	400 to 2000	> 2000
9-ft or less	1.05	$1.05+2.81\times10^{-4}(AADT-400)$	1.50
10-ft	1.02	$1.02+1.75\times10^{-4}(AADT-400)$	1.30
11-ft	1.01	$1.01+2.5\times10^{-5}(AADT-400)$	1.05
12-ft or more	1.00	1.00	1.00

$$CMF_{laneW} = (CMF_{ra} - 1) \times P_{ra} + 1.0$$

Where,
CMF_{laneW} = Crash Modification Factor for the effect of lane width on total accidents;
CMF_{ra} = Crash Modification Factor for lane width shown in TABLE
P_{ra} = by table

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For roadway variables not in base condition, a crash modification factor (CMF) is used. Here is an example for lane width.

Ref: Highway Safety Manual, 1st Edition by AASHTO

Crash Modification Factor for shoulder width

Shoulder Width	AADT (vehicles per day)		
	< 400	400 to 2000	> 2000
0-ft	1.10	$1.10 + 2.5 \times 10^{-4}$ (AADT - 400)	1.50
2-ft	1.07	$1.07 + 1.43 \times 10^{-4}$ (AADT - 400)	1.30
4-ft	1.02	$1.02 + 8.125 \times 10^{-5}$ (AADT - 400)	1.15
6-ft	1.00	1.00	1.00
8-ft or more	0.98	$0.98 + 6.875 \times 10^{-5}$ (AADT - 400)	0.87

NOTE: The collision types related to shoulder width to which this AMF applies include single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents.

- Another example for shoulder width

CMF for driveway density

$$\boxed{\text{CMF}} = \frac{0.2 + [0.05 - 0.05\ln(ADT)]DD}{0.2 + [0.05 - 0.05\ln(ADT)](5)} \qquad (13)$$

where:

ADT = annual average daily traffic volume of the roadway being evaluated (veh/day); and

DD = driveway density considering driveways on both sides of the highway (driveways per mile).

CMF for driveway density is a function of traffic and driveway density.

Read HSM Chapter 10 for other CMFs

Crash Severity Level on Rural Two-Lane Two-Way Roadway Segments

Crash Severity Level	% of Crashes
Fatal	1.3
Incapacitating Injury	5.4
Nonincapacitating Injury	10.9
Possible Injury	14.5
Total Fatal Plus Injury	32.1
PDO	67.9
Total	100

Remember these numbers are default numbers. Crash severity distribution may vary by state.

Safety Models

- Introduction
- Rural 2-lane model
- **Rural Multilane Model**
- Urban and Suburban Arterial Model

Base model for 4 leg signalized intersection

$$N_{spf} = e^{(-5.13+0.6\times Ln(AADT_{mai})+.2\times Ln(AADT_{\min}))}$$

Base model for 4 leg stop controlled intersection

$$N_{spf} = e^{(-8.56+0.6\times Ln(AADT_{mai})+.61\times Ln(AADT_{\min}))}$$

Base model for 3 leg stop controlled intersection

$$N_{spf} = e^{(-9.86+0.79\times Ln(AADT_{mai})+.49\times Ln(AADT_{\min}))}$$

Three SPFs for intersection on rural two-lane highways. Only traffic volume is considered here.

Base conditions

- Intersection skew angle 0°
- Intersection left-turn lanes None
- Intersection right-turn lanes None
- Lighting None

Other variables are in “base condition” that is defined here.

Example of CMF for intersections

Intersection type	Intersection traffic control	Number of approaches with left-turn lanes [a]			
		One approach	Two approaches	Three approaches	Four approaches
Three-leg intersection	Minor road stop control[b]	0.56	0.31	—	—
Four-leg intersection	Minor road stop control[b]	0.72	0.52	—	—
	Traffic signal	0.82	0.67	0.55	0.45

NOTE: [a] Stop-controlled approaches are not considered in determining the number of approaches with left-turn lanes
[b] Stop signs present on minor road approaches only.

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If the variable is not in base condition, use CMF. Here is the example for left-turn-lanes.

Ref: Highway Safety Manual, 1st Edition by AASHTO

Distribution

EXHIBIT 2. DEFAULT DISTRIBUTION FOR ACCIDENT SEVERITY LEVEL ON RURAL TWO-LANE HIGHWAYS

Accident severity level	Percentage of total accidents			
	Roadway segments[a]	Three-leg STOP-controlled intersections[b]	Four-leg STOP-controlled intersections[b]	Four-leg signalized intersections[b]
Fatal	1.3	1.1	1.9	0.4
Incapacitating Injury	5.4	5.0	6.3	4.1
Nonincapacitating injury	10.9	15.2	12.8	12.0
Possible injury	14.5	18.5	20.7	21.2
Total fatal plus injury	32.1	39.8	41.7	37.7
Property damage only	67.9	60.2	58.3	62.3
TOTAL	100.0	100.0	100.0	100.0

[a] Based on HSIS data for Illinois (1992), Michigan (1995), Minnesota (1996), and North Carolina (1995).
[b] Based on HSIS data for Michigan (1995) and Minnesota (1996).

- Default values for crash severity distribution

Ref: Highway Safety Manual, 1st Edition by AASHTO

Accident type and manner of collision	Percentage of total accidents: Roadway segments[a]	Three-leg STOP-controlled intersections[b]	Four-leg STOP-controlled intersections[b]	Four-leg signalized intersections[b]
SINGLE-VEHICLE ACCIDENTS				
Collision with animal	30.9	2.1	0.6	0.3
Collision with bicycle	0.3	0.7	0.3	1.0
Collision with parked vehicle	0.7	0.1	0.1	0.1
Collision with pedestrian	0.5	0.4	0.2	1.3
Overturned	2.3	2.1	0.6	0.4
Ran off road	28.1	10.4	4.5	1.9
Other single-vehicle accident	3.6	3.9	1.4	1.6
Total single-vehicle accidents	66.3	19.7	7.7	6.6
MULTIPLE-VEHICLE ACCIDENTS				
Angle collision	3.9	29.8	51.4	28.5
Head-on collision	1.9	2.0	1.4	1.8
Left-turn collision	4.2	6.4	5.9	9.0
Right-turn collision	0.6	0.4	0.2	0.4
Rear-end collision	13.9	26.2	17.2	36.2
Sideswipe opposite-direction collision	2.4	2.9	1.7	2.0
Sideswipe same-direction collision	2.6	4.5	4.4	5.5
Other multiple-vehicle collision	4.1	8.1	10.1	10.0
Total multiple-vehicle accidents	33.7	80.3	92.3	93.4
TOTAL ACCIDENTS	100.0	100.0	100.0	100.0

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Default crash type distribution, that may vary by state.

Ref: Highway Safety Manual, 1st Edition by AASHTO

Sample Application One (segment)

The Site/Facility

A rural two-lane tangent roadway segment.

The Question

What is the predicted average crash frequency of the roadway segment for a particular year?

The Facts

- 1.5-mi length
- Tangent roadway segment
- 10,000 veh/day
- 2% grade
- 6 driveways per mi
- 10-ft lane width
- 4-ft gravel shoulder
- Roadside hazard rating = 4

Assumptions

Collision type distributions used are the default values presented in HSM

The calibration factor is assumed to be 1.10.

Now it is time to go over an sample to show how the safety model works.

Ref: Highway Safety Manual, 1st Edition by AASHTO

Calculations

$$N_{spf} = AADT \times L \times 365 \times 10^{-6} \times e^{-0.312}$$
$$= 10{,}000 \times 1.5 \times 365 \times 10^{-6} \times e^{-0.312}$$
$$= 4.0008\_crashes/year$$

Lane width CMF

$$CMF_{laneW} = (CMF_{ra} - 1) \times P_{ra} + 1.0$$
$$= (1.3 - 1.0) \times 0.573 + 1$$
$$1.17$$

Combined CMFs = 1.38

for lane width	Shoulder width	Horizontal curve	Grade	Driveway	Centerline rumble strips	Passing lane	Left turn lane	roadside	lighting	Automatic enforcement
1.17	1.09	1.00	1.00	1.01	1.00	1.00	1.00	1.07	1.00	1.00

Final result=6.084 =6.1 crashes/year

Note, it makes no sense to keep more than one decimal point in final result.

Sample Application Two (segment)

What is the predicted average crash frequency of the roadway segment for a particular year?

The Facts

- 0.1-mi length
- Curved roadway segment
- 8,000 veh/day
- 1% grade
- 1,200-ft horizontal curve radius
- No spiral transition
- 0 driveways per mi
- 11-ft lane width
- 2-ft gravel shoulder
- Roadside hazard rating = 5
- 0.1-mi horizontal curve length
- 0.04 superelevation rate

Assumptions

- Collision type distributions have been adapted to local experience. The percentage of total crashes representing single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes is 78%.
- The calibration factor is assumed to be 1.10.
- Design speed = 60 mph
- Maximum superelevation rate, e_{max} = 6%

For a more comprehensive application like Sample Applications two, three, four and five, use the Excel Program.

Ref: Highway Safety Manual, 1st Edition by AASHTO

Sample Application Three (3ST Intersection)

The Question

What is the predicted average crash frequency of the stop-controlled intersection for a particular year?

The Facts

- 3 legs
- Minor-road stop control
- No right-turn lanes on major road
- No left-turn lanes on major road
- 30-degree skew angle
- AADT of major road = 8,000 veh/day
- AADT of minor road = 1,000 veh/day
- Intersection lighting is present

Assumptions

- Collision type distributions used are the default values from Exhibit 10-12.
- The proportion of crashes that occur at night are not known, so the default proportion for nighttime crashes is assumed.
- The calibration factor is assumed to be 1.50.

Ref: Highway Safety Manual, 1st Edition by AASHTO

Sample Application Four (4SG Intersection)

The Question

What is the predicted average crash frequency of the signalized intersection for a particular year?

The Facts

- 4 legs
- 1 right-turn lane on one approach
- Signalized intersection
- 90-degree intersection angle
- No lighting present
- AADT of major road = 10,000 veh/day
- AADT of minor road = 2,000 veh/day
- 1 left-turn lane on each of two approaches

Assumptions

- Collision type distributions used are the default values from Exhibit 10-12.
- The calibration factor is assumed to be 1.30.

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Ref: Highway Safety Manual, 1st Edition by AASHTO

Sample Application Five (three sites)

The Project

A project of interest consists of three sites: a rural two-lane tangent segment; a rural two-lane curved segment; and a three-leg intersection with minor-road stop control. (This project is a compilation of roadway segments and intersections from Sample Problems 1, 2 and 3.)

The Question

What is the expected average crash frequency of the project for a particular year incorporating both the predicted average crash frequencies from Sample Problems 1, 2 and 3 and the observed crash frequencies using the **site-specific EB Method**?

The Facts

- 2 roadway segments (2U tangent segment, 2U curved segment)
- 1 intersection (3ST intersection)
- 15 observed crashes (2U tangent segment: 10 crashes; 2U curved segment: 2 crashes; 3ST intersection: 3 crashes)

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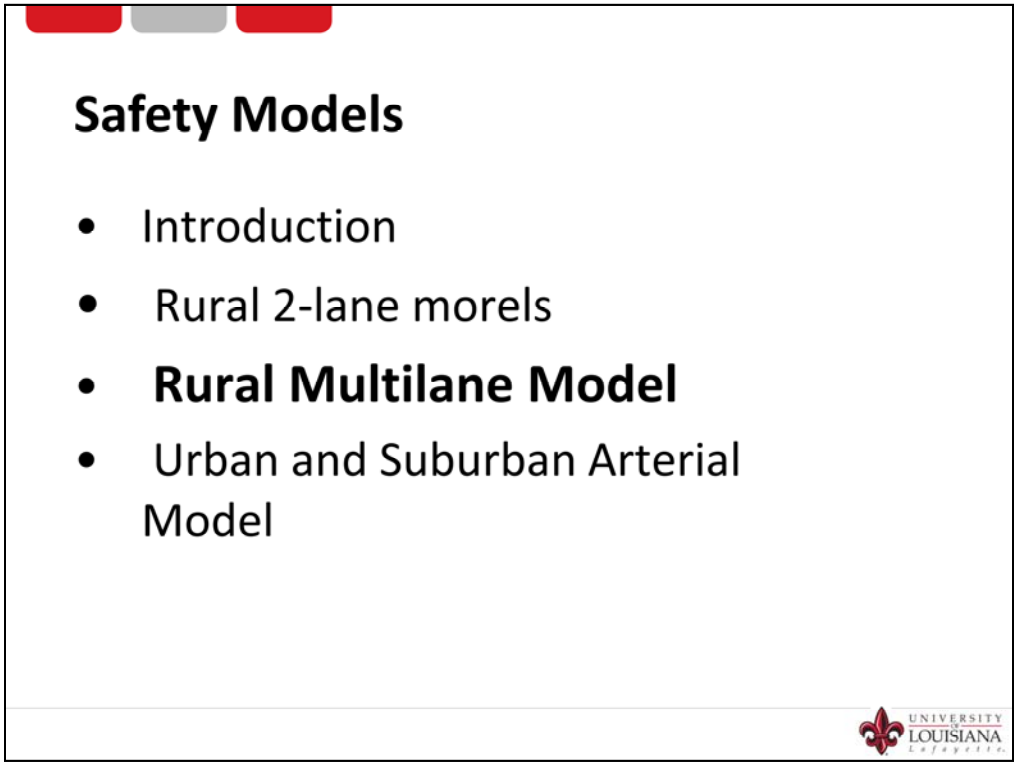
Ref: Highway Safety Manual, 1st Edition by AASHTO

Introduction to Excel Worksheet

- Posted online
- Must be utilized for homework

The Excel Program developed by Dr. Karen Dixon is available online.



Three chapters in the first edition of the HSM deal with safety models for three types of highways.

Note the difference in segment from the previous model on rural two-lane highways.

Rural Multilane Models

- Separate safety prediction procedures have been developed for **divided** (4D) and **undivided** (4U) roadway segments and for four types of at-grade intersections.

4D – Divided highways are non freeway facilities (i.e., facilities without full control of access) that have the lanes in the two directions of travel separated by a raised, depressed or flush median which is not designed to be traversed by a vehicle; this may include raised or depressed medians, with or without a physical median barrier, flush medians with physical median barriers.

SPF for both divided and undivided rural 4-lane highway segment

$$N_{spf} = e^{(a+b\times Ln(AADT)+Ln(L))}$$

$$k = \frac{1}{e^{(c+Ln(L))}}$$

N_{spf} = base total expected average crash frequency for a roadway segment;
AADT = annual average daily traffic (vehicles per day) on roadway segment;
L = length of roadway segment (miles);
K = overdispersion factor
a, b, c = regression coefficients

AADT range from 0 to 89,300 vehicles

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Base model is the same for both divided and undivided segments.
K is used for EB application.

Coefficients for 4-lane Undivided Rural Roadway

Crash Severity Level	a	b	c
total	-9.653	1.176	1.675
Fatal and injury	-9.410	1.094	1.796
*Fatal and injury	-8.577	0.938	2.003

* Using KABCO scale and level C is not included

Coefficients for 4-lane Divided Rural Roadway

Crash Severity Level	a	b	c
total	-9.025	1.049	1.549
Fatal and injury	-8.837	0.958	1.687
*Fatal and injury	-8.505	0.847	1.740

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Discuss the difference in coefficients between two types of segments and among three crash severity levels.

Base Condition for <u>Undivided</u> Rural Multilane Highways

• Lane width (LW)	12 feet
• Shoulder width	6 feet
• Shoulder type	Paved
• Side slopes	1V:7H or flatter
• Lighting	None
• Automated speed enforcement	None

Again, define base conditions.

Base Condition for <u>Divided</u> Rural Multilane Highways

• Lane width (LW)	12 feet
• Right Shoulder width	8 feet
• Median Width	30 feet
• Lighting	None
• Automated speed enforcement	None

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- Base condition definition

Collision type	Proportion of crashes by collision type and crash severity level			
	Severity level			
	Total	Fatal and injury	Fatal and injury[a]	PDO
Head-on	0.009	0.029	0.043	0.001
Sideswipe	0.098	0.048	0.044	0.120
Rear-end	0.246	0.305	0.217	0.220
Angle	0.356	0.352	0.348	0.358
Single	0.238	0.238	0.304	0.237
Other	0.053	0.028	0.044	0.064

NOTE: [a] Using the KABCO scale, these include only KAB accidents. Crashes with severity level C (possible injury) are not included

Undivided

Collision type	Proportion of crashes by collision type and crash severity level			
	Severity level			
	Total	Fatal and injury	Fatal and injury[a]	PDO
Head-on	0.006	0.013	0.018	0.002
Sideswipe	0.043	0.027	0.022	0.053
Rear-end	0.116	0.163	0.114	0.088
Angle	0.043	0.048	0.045	0.041
Single	0.768	0.727	0.778	0.792
Other	0.024	0.022	0.023	0.024

NOTE: [a] Using the KABCO scale, these include only KAB accidents. Crashes with severity level C (possible injury) are not included.

Divided

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Default table for distribution of crash type.

Ref: Highway Safety Manual, 1st Edition by AASHTO

Example of CMF for Segments (shoulder width)

Shoulder Width	Annual Average Daily Traffic (AADT) (vehicles/day)		
	< 400	400 to 2000	> 2000
0-ft	1.10	$1.10 + 2.5 \times 10^{-4}$ (AADT - 400)	1.50
2-ft	1.07	$1.07 + 1.43 \times 10^{-4}$ (AADT - 400)	1.30
4-ft	1.02	$1.02 + 8.125 \times 10^{-5}$ (AADT - 400)	1.15
6-ft	1.00	1.00	1.00
8-ft or more	0.98	$0.98 + 6.875 \times 10^{-5}$ (AADT - 400)	0.87

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CMF for variables not in base condition. Here is shoulder width example.

Ref: Highway Safety Manual, 1st Edition by AASHTO

SPF for Intersections on Rural 4-lane Highways

$$N_{spf} = e^{[a+b\times \ln(AADT_{main})+c\times Ln(AADT_{\min})]}$$

or

$$N_{spf} = e^{[a+d\times Ln(AADT_{total})]}$$

Where,

N_{spf} = SPF estimate of intersection-related expected average crash frequency for base conditions;

$AADT_{ma}$ = AADT (vehicles per day) for major road approaches;

$AADT_{min}$ = AADT (vehicles per day) for minor road approaches;

$AADT_{tot}$ = AADT (vehicles per day) for minor and major roads combined approaches;

a, b, c, d = regression coefficients.

For intersections, two SPFs are introduced, they are slightly different in treating AADT.

AADT Limitations

3ST: $AADT_{maj}$ 0 to 78,300 vehicles per day and $AADT_{min}$ 0 to 23,000 vehicles per day

4ST: $AADT_{maj}$ 0 to 78,300 vehicles per day and $AADT_{min}$ 0 to 7,400 vehicles per day

4SG: $AADT_{maj}$ 0 to 43,500 vehicles per day and $AADT_{min}$ 0 to 18,500 vehicles per day

Since the data used for model development is limited in AADT, it is important to point out the AADT limitations.

Coefficients for 3 and 4-leg Intersections with Minor road Stop Control

Crash Severity Level	a	b	c	Overdispersion parameter k
4ST total	-10.008	0.848	.448	0.494
4ST Fatal and injury	-11.554	0.888	0.525	0.742
4ST Fatal and injury*	-10.734	0.828	0.412	0.665
3ST total	-12.526	1.204	0.236	0.460
3ST Fatal and injury	-12.664	1.107	0.272	0.569
3ST Fatal and Injury**	-11.989	1.013	0.228	0.566

Coefficients for 4-leg Signalized Intersections

Crash Severity Level	a	b	c	Overdispersion parameter k
4SG total	-9.025	1.049	1.549	0.277
4SG Fatal and injury	-8.837	0.958	1.687	0.218
*4SG Fatal and injury	-8.505	0.847	1.740	0.566

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- Table of coefficients for intersection models

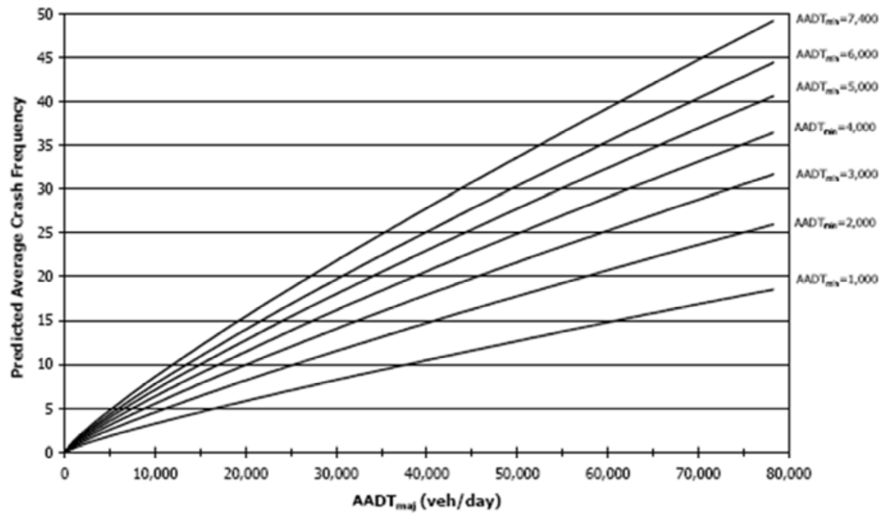
Intersection base condition

- The SPFs for four-leg signalized intersections (4SG) on rural multilane highways have no specific base conditions

- The SPFs for three- and four-leg stop-controlled intersections (3ST and 4ST) on rural multilane highways are applicable to the following base conditions:
  - Intersection skew angle — 0°
  - Intersection left-turn lanes — 0, except on stop-controlled approaches
  - Intersection right-turn lanes — 0, except on stop-controlled approaches
  - Lighting — None

- Intersection base condition

Graphical Form of SPF for Four-leg STOP-controlled Intersections



Ref: Highway Safety Manual, 1st Edition by AASHTO

Example CMF for Installation of Left-Turn Lanes on Intersection Approaches.

Intersection type	Crash Severity Level	Number of non-stop-controlled approaches with left-turn lanes [a]	
		One approach	Two approaches
Three-leg minor road STOP control[b]	Total	0.56	-
	Fatal and Injury	0.45	-
Four-leg minor road STOP control[b]	Total	0.72	0.52
	Fatal and Injury	0.65	0.42

NOTE: [a] STOP-controlled approaches are not considered in determining the number of approaches with left-turn lanes

[b] STOP signs present on minor road approaches only.

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For variables not in base condition, use CMF.

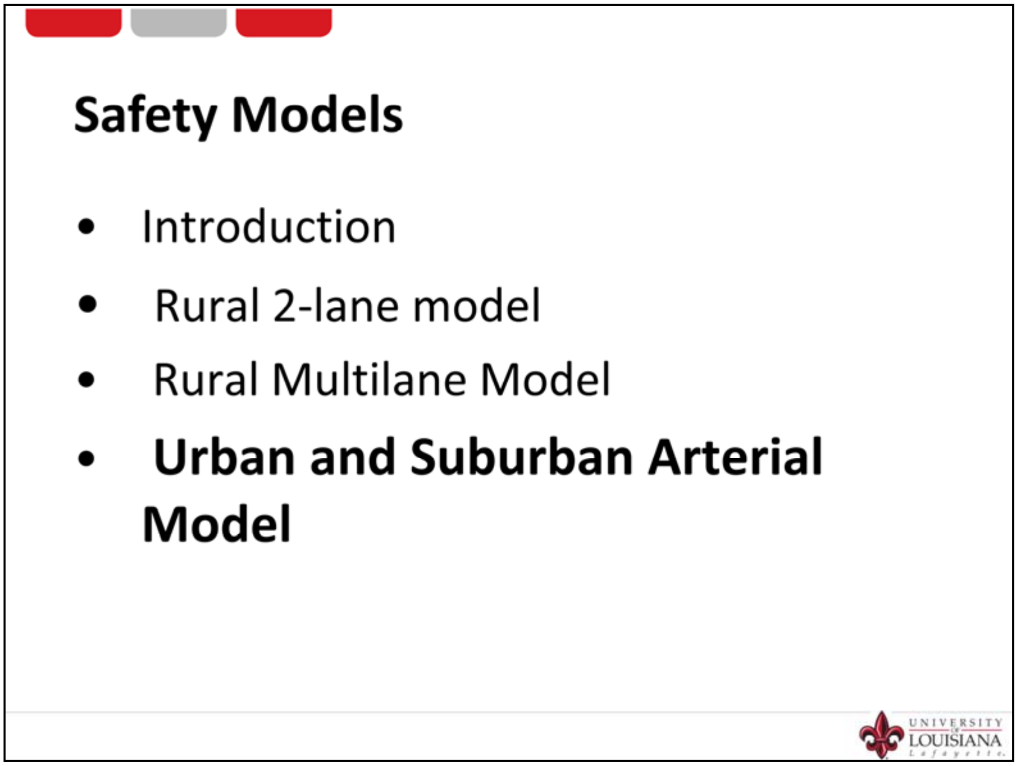
Ref: Highway Safety Manual, 1st Edition by AASHTO

Collision type	Proportion of crashes by severity level							
	Three-leg intersections with minor road stop control				Four-leg intersections with minor road stop control			
	Total	Fatal and injury	Fatal and injury[a]	PDO	Total	Fatal and injury	Fatal and injury[a]	PDO
Head-on	0.029	0.043	0.052	0.020	0.016	0.018	0.023	0.015
Sideswipe	0.133	0.058	0.057	0.179	0.107	0.042	0.040	0.156
Rear-end	0.289	0.247	0.142	0.315	0.228	0.213	0.108	0.240
Angle	0.263	0.369	0.381	0.198	0.395	0.534	0.571	0.292
Single	0.234	0.219	0.284	0.244	0.202	0.148	0.199	0.243
Other	0.052	0.064	0.084	0.044	0.051	0.046	0.059	0.055
Collision type	Three-leg signalized intersections				Four-leg signalized intersections			
	Total	Fatal and injury	Fatal and injury[a]	PDO	Total	Fatal and injury	Fatal and injury[a]	PDO
Head-on	--	--	--	--	0.054	0.083	0.093	0.034
Sideswipe	--	--	--	--	0.106	0.047	0.039	0.147
Rear-end	--	--	--	--	0.492	0.472	0.314	0.505
Angle	--	--	--	--	0.256	0.315	0.407	0.215
Single	--	--	--	--	0.062	0.041	0.078	0.077
Other	--	--	--	--	0.030	0.041	0.069	0.023

NOTE: [a] Using the KABCO scale, these include only KAB accidents. Crashes with severity level C (possible inju

- Table for default values on crash type distribution at intersections

Ref: Highway Safety Manual, 1st Edition by AASHTO



Three chapters in the first edition of HSM deal with safety models for three types of highways.

Analysis Units

Roadway Segment	Two-lane undivided arterials **(2U)**
	Three-lane arterials including a center two-way left-turn lane (TWLTL) **(3T)**
	Four-lane undivided arterials **(4U)**
	Four-lane divided arterials (i.e., including a raised or depressed median) **(4D)**
	Five-lane arterials including a center TWLTL **(5T)**
Intersections	Unsignalized three-leg intersection (Stop control on minor-road approaches) **(3ST)**
	Signalized three-leg intersections **(3SG)**
	Unsignalized four-leg intersection (Stop control on minor-road approaches) **(4ST)**
	Signalized four-leg intersection **(4SG)**

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Urban and Suburban Arterial Model is the most complicated model due to the roadways comprehensive safety performance.

Nine models do not cover all types of roads in urban and suburban roadways.

Models for Urban and Suburban Arterials

Segment

$$N_{pre} = ((\underbrace{N_{spf} \times \prod CMF_i)}_{\text{Part 1}} + \underbrace{N_{ped}}_{\text{Part 2}} + \underbrace{N_{bike}}_{\text{Part 3}}) \times C$$

Where,

N_{pre} = *predicted average crash frequency for a specific year*

N_{spf} = *predicted average crash frequency determined for base conditions of the SPF developed*

N_{ped} = *predicted average number of vehicle-pedestrian collisions per year*

N_{bike} = *predicted average number of vehicle-bicycle collisions per year*

CMF_i *Crash Modification Factors*

C= calibration factor to adjust SPF for local conditions

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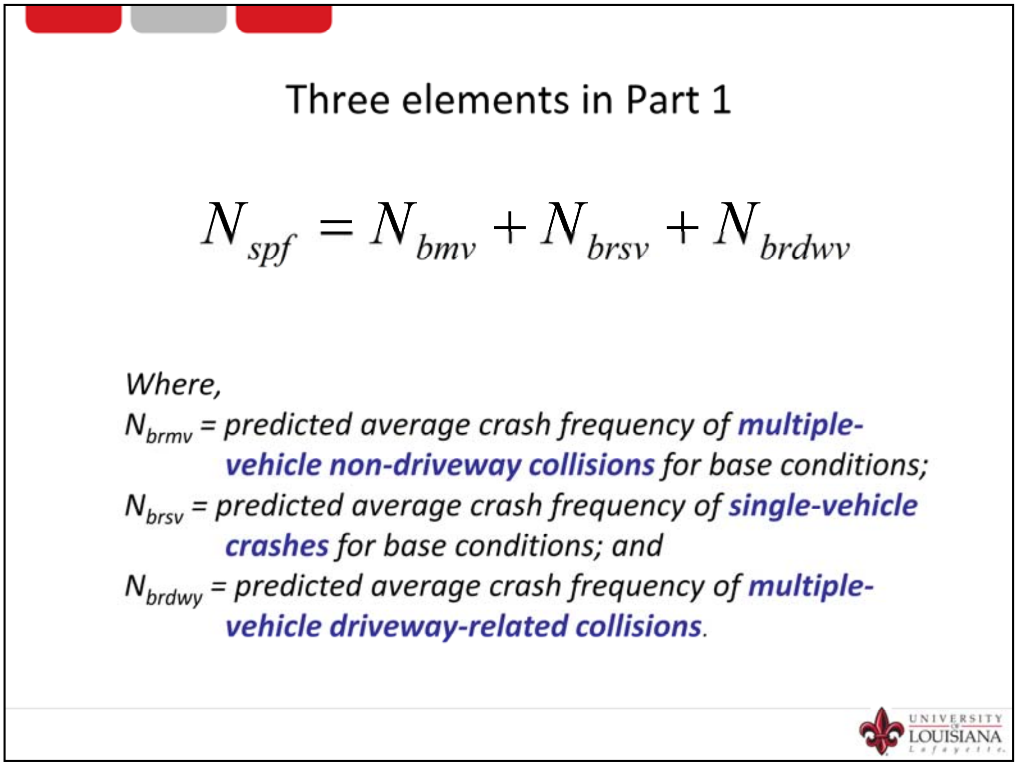
The SPF consists of three parts because pedestrian and bicycle traffic must be considered. It is time to remind students that 10% of total fatalities are pedestrians annually.



Even part one has three elements by crash types.

Summary

$$N_{predicted-rs} = \left(N_{br} + N_{pedr} + N_{bi\ker}\right) \times C_r$$

$$N_{br} = \left(N_{brmv} + N_{brsv} + N_{brdwy}\right) \times (CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{5r})$$

- Multiple-vehicle non driveway collisions;
- Single-vehicle crashes;
- Multiple-vehicle driveway-related collisions;

- Vehicle-pedestrian collisions;
- Vehicle-bicycle collisions.

It is easy to get lost in this model, let's summarize the model again in equations.

SPF for multiple-vehicle non-driveway collisions (part 1.1)

$$N_{brmv} = e^{a + b \times Ln(AADT) + Ln(L)}$$

Where,
AADT = average daily traffic volume (vehicles/day) on roadway segment;
L = length of roadway segment (mi);
a, b = regression coefficients

Coefficients for Multiple-Vehicle Non-driveway Collisions on Five Different Types of Roadway Segments

Road type	Coefficients used in Equation 12-10 Intercept (a)	AADT (b)	Overdispersion parameter (k)
Total crashes			
2U	-15.22	1.68	0.84
3T	-12.40	1.41	0.66
4U	-11.63	1.33	1.01
4D	-12.34	1.36	1.32
5T	-9.70	1.17	0.81
Fatal-and-injury crashes			
2U	-16.22	1.66	0.65
3T	-16.45	1.69	0.59
4U	-12.08	1.25	0.99
4D	-12.76	1.28	1.31
5T	-10.47	1.12	0.62
Property-damage-only crashes			
2U	-15.62	1.69	0.87
3T	-11.95	1.33	0.59
4U	-12.53	1.38	1.08
4D	-12.81	1.38	1.34
5T	-9.97	1.17	0.88

Ref: Highway Safety Manual, 1st Edition by AASHTO

Distribution of Multiple-Vehicle Non-driveway Collisions for Segments by Manner of Collision Type

Collision type	2U FI	2U PDO	3T FI	3T PDO	4U FI	4U PDO	4D FI	4D PDO	5T FI	5T PDO
Rear-end collision	0.730	0.778	0.845	0.842	0.511	0.506	0.832	0.662	0.846	0.651
Head-on collision	0.068	0.004	0.034	0.020	0.077	0.004	0.020	0.007	0.021	0.004
Angle collision	0.085	0.079	0.069	0.020	0.181	0.130	0.040	0.036	0.050	0.059
Sideswipe, same direction	0.015	0.031	0.001	0.078	0.093	0.249	0.050	0.223	0.061	0.248
Sideswipe, opposite direction	0.073	0.055	0.017	0.020	0.082	0.031	0.010	0.001	0.004	0.009
Other multiple-vehicle collisions	0.029	0.053	0.034	0.020	0.056	0.080	0.048	0.071	0.018	0.029

Proportion of crashes by severity level for specific road types

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Ref: Highway Safety Manual, 1st Edition by AASHTO

SPF for single-vehicle crashes (part 1.2)

$$N_{brsv} = e^{a + b \times Ln(AADT) + Ln(L)}$$

Where,
AADT = average daily traffic volume (vehicles/day) on roadway segment;
L = length of roadway segment (mi);
a, b = regression coefficients

By now, model becomes self-explanatory.

Coefficients for Single-vehicle Crashes on Five Different Types of Roadway Segments

Road type	Coefficients used in Equation 12-11 Intercept (a)	Coefficients used in Equation 12-11 AADT (b)	Overdispersion parameter (k)
Total crashes			
2U	-5.47	0.56	0.81
3T	-5.74	0.54	1.37
4U	-7.99	0.81	0.91
4D	-5.05	0.47	0.86
5T	-4.82	0.54	0.52
Fatal-and-injury crashes			
2U	-3.96	0.23	0.50
3T	-6.37	0.47	1.06
4U	-7.37	0.61	0.54
4D	-8.71	0.66	0.28
5T	-4.43	0.35	0.36
Property-damage-only crashes			
2U	-6.51	0.64	0.87
3T	-6.29	0.56	1.93
4U	-8.50	0.84	0.97
4D	-5.04	0.45	1.06
5T	-5.83	0.61	0.55

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Ref: Highway Safety Manual, 1st Edition by AASHTO

SPF for Multiple-Vehicle Driveway-Related Collisions (part 1.3)

$$N_{brdwy} = \sum_{\substack{all \\ driveway \\ types}} n_j \times N_j \times \left(\frac{AADT}{15{,}000}\right)^t$$

Where,

N_j = Number of driveway-related collisions per driveway per year for driveway type j

n_j = number of driveways within roadway segment of driveway type j including all driveways on both sides of the road

t = coefficient for traffic volume adjustment

Seven specific driveway types

- Major commercial driveways (serve sites with 50 or more parking spaces)
- Minor commercial driveways (serve sites with less than 50 parking spaces)
- Major industrial/institutional driveways
- Minor industrial/institutional driveways
- Major residential driveways
- Minor residential driveways
- Other driveways

Coefficients for Multiple-Vehicle Driveway Related Collisions on Five Different Types of Roadway Segments

Driveway type (j)	Coefficients for specific roadway types				
	2U	3T	4U	4D	5T
Number of driveway-related collisions per driveway per year (N_j)					
Major commercial	0.158	0.102	0.182	0.033	0.165
Minor commercial	0.050	0.032	0.058	0.011	0.053
Major industrial/institutional	0.172	0.110	0.198	0.036	0.181
Minor industrial/institutional	0.023	0.015	0.026	0.005	0.024
Major residential	0.083	0.053	0.096	0.018	0.087
Minor residential	0.016	0.010	0.018	0.003	0.016
Other	0.025	0.016	0.029	0.005	0.027
Regression coefficient for AADT (t)					
All driveways	1.000	1.000	1.172	1.106	1.172
Overdispersion parameter (k)					
All driveways	0.81	1.10	0.81	1.39	0.10
Proportion of fatal-and-injury crashes (f_{dwy})					
All driveways	0.323	0.243	0.342	0.284	0.269
Proportion of property-damage-only crashes					
All driveways	0.677	0.757	0.658	0.716	0.731

Note: Includes only unsignalized driveways; signalized driveways are analyzed as signalized intersections. M driveways serve 50 or more parking spaces; minor driveways serve less than 50 parking spaces.

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Ref: Highway Safety Manual, 1st Edition by AASHTO

SPF for Vehicle-Pedestrian Collisions (part 2)

$$N_{pedr} = N_{br} \times f_{pedr}$$

$$N_{br} = \left(N_{brmv} + N_{brsv} + N_{brdwy}\right) \times (CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{5r})$$

Where, f_{pedr} = pedestrian accident adjustment factor.

Road type	Pedestrian Accident Adjustment Factor (f_{pedr})	
	Posted Speed 30 mph or Lower	Posted Speed Greater than 30 mph
2U	0.036	0.005
3T	0.041	0.013
4U	0.022	0.009
4D	0.067	0.019
5T	0.030	0.023

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All pedestrian collisions resulting from this adjustment factor is treated as fatal-and-injury crashes and none

Ref: Highway Safety Manual, 1st Edition by AASHTO

SPF for Vehicle-Bicycle Collisions (part 3)

$$N_{biker} = N_{br} \times f_{biker}$$

$$N_{br} = \left(N_{brmv} + N_{brsv} + N_{brdwy}\right) \times (CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{5r})$$

Where, f_{biker} = bicycle accident adjustment factor.

Road type	Bicycle Accident Adjustment Factor (f_{biker})	
	Posted Speed 30 mph or Lower	Posted Speed Greater than 30 mph
2U	0.018	0.004
3T	0.027	0.007
4U	0.011	0.002
4D	0.013	0.005
5T	0.050	0.012

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All bicycle collisions resulting from this adjustment factor are treated as fatal-and-injury crashes and none as property-damage-only crashes. Source: HSIS data for Washington (2002-2006)

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Ref: Highway Safety Manual, 1st Edition by AASHTO

Review

$$N_{predicted-rs} = (N_{br} + N_{pedr} + N_{biker}) \times C_r$$

$$N_{br} = (N_{brmv} + N_{brsv} + N_{brdwy}) \times (CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{5r})$$

- Multiple-vehicle non driveway collisions;
- Single-vehicle crashes;
- Multiple-vehicle driveway-related collisions;
- Vehicle-pedestrian collisions = $N_{pedr} = N_{br} \times f_{pedr}$
- Vehicle-bicycle collisions = $N_{biker} = N_{br} \times f_{biker}$

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Base Condition

Type of on-street parking (none/parallel/angle)	None
Proportion of curb length with on-street parking	--
Median width (ft) - for divided only	15
Lighting (present / not present)	Not Present
Auto speed enforcement (present / not present)	Not Present
Major commercial driveways (number)	--
Minor commercial driveways (number)	--
Major industrial / institutional driveways (number)	--
Minor industrial / institutional driveways (number)	--
Major residential driveways (number)	--
Minor residential driveways (number)	--
Other driveways (number)	--
Speed Category	--
Roadside fixed object density (fixed objects / mi)	0
Offset to roadside fixed objects (ft) [If greater than 30 or Not Present, input 30]	30

CMF for On Street Parking

$$CMF = 1 + p_{pk}(f_{pk} - 1.0)$$

Where,

f_{pk} = factor from the following table

p_{pk} = proportion of curb length with on-street parking = (0.5 Lpk/L);

L_{pk} = sum of curb length with on-street parking for both sides of the road combined (miles);

L = length of roadway segment (miles).

Road type	Type of parking and land use			
	Parallel parking		Angle parking	
	Residential/other	Commercial or industrial/ institutional	Residential/other	Commercial or industrial/ institutional
2U	1.465	2.074	3.428	4.853
3T	1.465	2.074	3.428	4.853
4U	1.100	1.709	2.574	3.999
4D	1.100	1.709	2.574	3.999
5T	1.100	1.709	2.574	3.999

Ref: Highway Safety Manual, 1st Edition by AASHTO

Urban & Suburban Arterial **Intersections**

$$N_{predicted-\text{int}} = \left(N_{bi} + N_{pedi} + N_{bikei}\right) \times C_i$$

$$N_{bi} = \left(N_{bimv} + N_{bisv}\right) \times \left(CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{6r}\right)$$

- **Multiple-vehicle & Single-vehicle collisions**
- **Vehicle-pedestrian collisions**
- **Vehicle-bicycle collisions**

For intersections there are also several parts.

SPF for Multiple-Vehicle Collisions (Intersection)

$$N_{bimv} = e^{a+b\times Ln(AADT_{mai})+c\times Ln(AADT_{\min})}$$

Where,

$AADT_{maj}$ = average daily traffic volume (vehicles/day) for major road (both directions of travel combined);

$AADT_{min}$ = average daily traffic volume (vehicles/day) for minor road (both directions of travel combined);

a, b, c = regression coefficients

Coefficients for Multiple-Vehicle Collisions at Intersections

Intersection type	Coefficients used in Equation 12-21			Over-dispersion parameter (k)
	Intercept (a)	$AADT_{maj}$ (b)	$AADT_{min}$ (c)	
Total crashes				
3ST	-13.36	1.11	0.41	0.80
3SG	-12.13	1.11	0.26	0.33
4ST	-8.90	0.82	0.25	0.40
4SG	-10.99	1.07	0.23	0.39
Fatal-and-injury crashes				
3ST	-14.01	1.16	0.30	0.69
3SG	-11.58	1.02	0.17	0.30
4ST	-11.13	0.93	0.28	0.48
4SG	-13.14	1.18	0.22	0.33
Property-damage-only crashes				
3ST	-15.38	1.20	0.51	0.77
3SG	-13.24	1.14	0.30	0.36
4ST	-8.74	0.77	0.23	0.40
4SG	-11.02	1.02	0.24	0.44

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Ref: Highway Safety Manual, 1st Edition by AASHTO

SPF for Single-Vehicle Collisions (Intersection)

$$N_{bisv} = e^{a+b\times Ln(AADT_{mai})+c\times Ln(AADT_{\min})}$$

Where,

$AADT_{maj}$ = average daily traffic volume (vehicles/day) for major road (both directions of travel combined);

$AADT_{min}$ = average daily traffic volume (vehicles/day) for minor road (both directions of travel combined);

a, b, c = regression coefficients

Coefficients for Single-Vehicle Collisions at Intersections

Intersection type	Coefficients used in Equation 12-24 Intercept (a)	$AADT_{maj}$ (b)	$AADT_{min}$ (c)	Over-dispersion parameter (k)
Total crashes				
3ST	-6.81	0.16	0.51	1.14
3SG	-9.02	0.42	0.40	0.36
4ST	-5.33	0.33	0.12	0.65
4SG	-10.21	0.68	0.27	0.36
Fatal-and-injury crashes				
3ST				
3SG	-9.75	0.27	0.51	0.24
4ST				
4SG	-9.25	0.43	0.29	0.09
Property-damage-only crashes				
3ST	-8.36	0.25	0.55	1.29
3SG	-9.08	0.45	0.33	0.53
4ST	-7.04	0.36	0.25	0.54
4SG	-11.34	0.78	0.25	0.44

Note: Where no models are available, Equation 12-27 is used.

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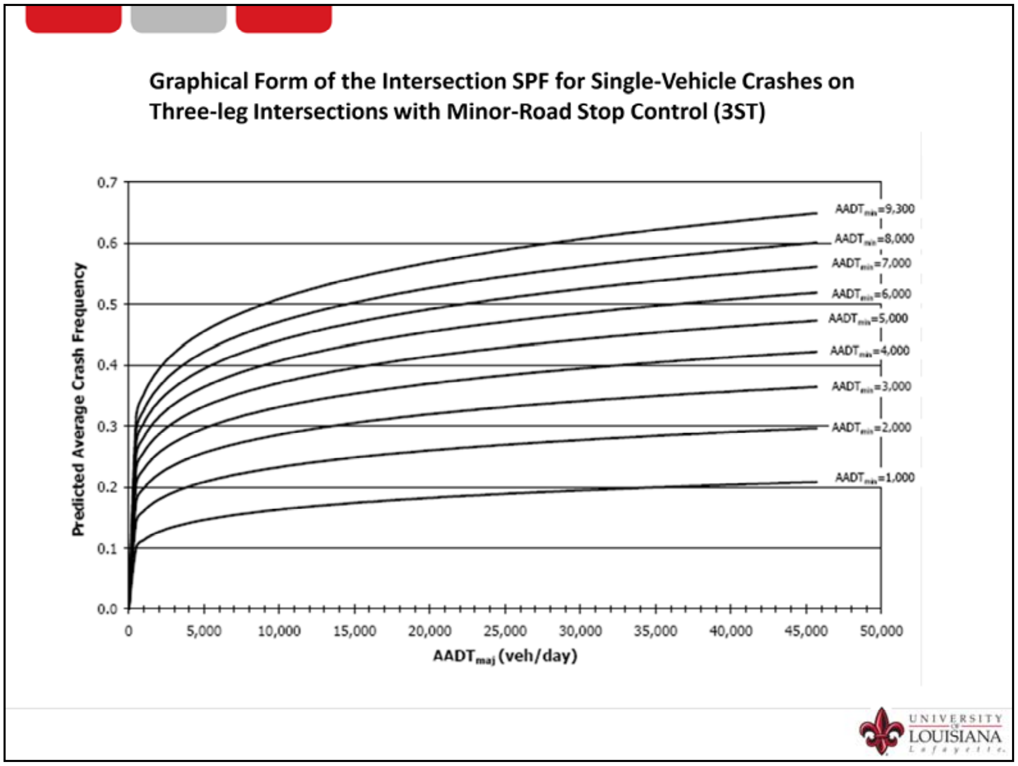
Ref: Highway Safety Manual, 1st Edition by AASHTO



Ref: Highway Safety Manual, 1st Edition by AASHTO

The model for estimating vehicle-pedestrian collisions at signalized intersections:

$$N_{ped} = N_{pedbase} \times \prod CMF_{ip}$$

SPF for Vehicle-Pedestrian Collisions (Signalized Intersection)

$$N_{oedbase} = e^{a+b\times Ln(AADT_{tot})+c\times Ln(\frac{AADT_{\min}}{AADT_{maj}})+d\times Ln(PedVol)+e\times n_{lanes}}$$

Where,

$AADT_{tot}$ *= sum of the average daily traffic volumes (vehicles per day) for the major and minor roads (= $AADT_{maj}$ + $AADT_{min}$);*

PedVol *= sum of daily pedestrian volumes (pedestrians/day) crossing all intersection legs;*

n_{lanes} *= maximum number of traffic lanes crossed by a pedestrian in any crossing maneuver at the intersection considering the presence of refuge islands;*

a,b,c,d,e *= regression coefficients.*

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Coefficients for Vehicle-Pedestrian Collisions at Signalized Intersections

Crash Severity Level	a	b	c	d	e	Overdispersion parameter k
3SG total	-6.60	0.05	0.24	0.41	0.09	0.52
4SG total	-9.53	0.40	0.26	0.45	0.04	0.25

Estimates of Pedestrian Crossing Volumes Based on General Level of Pedestrian Activity

General level of pedestrian activity	Estimate of PedVol (pedestrians/day) for use in Equation 12-29	
	3SG intersections	4SG intersections
High	1,700	3,200
Medium-high	750	1,500
Medium	400	700
Medium-low	120	240
Low	20	50

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Ref: Highway Safety Manual, 1st Edition by AASHTO

SPF for Vehicle-Pedestrian Collisions (Stop Controlled Intersection)

$$N_{pedi} = N_{br} \times f_{pedi}$$

$$N_{bi} = \left(N_{bimv} + N_{bisv}\right) \times \left(CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{6r}\right)$$

Where, f_{pedi} = pedestrian accident adjustment factor.

Intersection Type	F_{pedi}
3ST	0.021
4ST	0.022

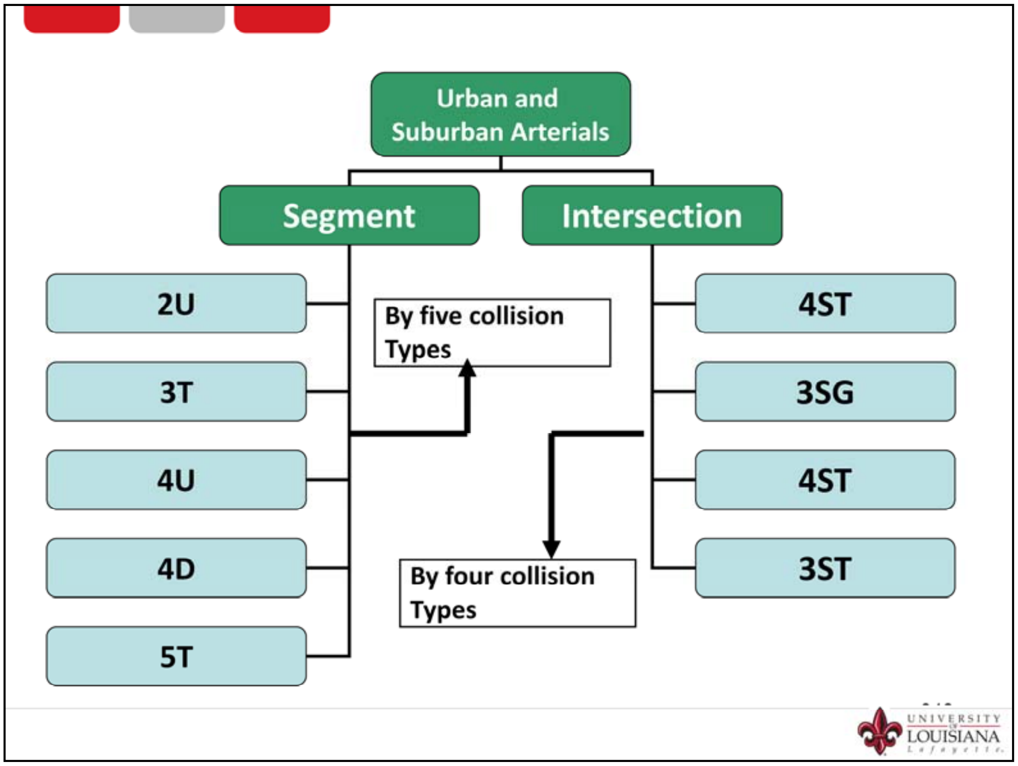
SPF for Vehicle-Bicycle Collisions

$$N_{bikei} = N_{bi} \times f_{bikei}$$

$$N_{bi} = \left(N_{bimv} + N_{bisv}\right) \times (CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{6r})$$

Where, f_{bikei} = bicycle accident adjustment factor.

Intersection Type	f_{bikei}
3ST	0.016
3SG	0.011
4ST	0.018
4SG	0.015



Again, let's look at the safety models for urban and suburban roadways. For segments, there are five types and each type of segment; there are five collision types. For intersections, there are four types and each type of intersection; four types of collisions are considered.

Review

$$N_{predicted-\text{int}} = \left(N_{bi} + N_{pedi} + N_{bikei}\right) \times C_i$$

$$N_{bi} = \left(N_{bimv} + N_{bisv}\right) \times (CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{6r})$$

- **Multiple-vehicle & Single-vehicle collisions**
- **Vehicle-pedestrian collisions= by type of intersection**
- **Vehicle-bicycle collisions=** $N_{bikei} = N_{bi} \times f_{bikei}$

Base Condition

Data for unsignalized intersections only:	--
Number of major-road approaches with left-turn lanes (0,1,2)	0
Number of major-road approaches with right-turn lanes (0,1,2)	0
Data for signalized intersections only:	--
Number of approaches with left-turn lanes (0,1,2,3,4) [for 3SG, use maximum value of 3]	0
Number of approaches with right-turn lanes (0,1,2,3,4) [for 3SG, use maximum value of 3]	0
Number of approaches with left-turn signal phasing [for 3SG, use maximum value of 3]	--
Type of left-turn signal phasing for Leg #1	Permissive
Type of left-turn signal phasing for Leg #2	--
Type of left-turn signal phasing for Leg #3	--
Type of left-turn signal phasing for Leg #4 (if applicable)	--
Number of approaches with right-turn-on-red prohibited [for 3SG, use maximum value of 3]	0
Intersection red light cameras (present/not present)	Not Present
Sum of all pedestrian crossing volumes (PedVol) -- Signalized intersections only	
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	--
Number of bus stops within 300 m (1,000 ft) of the intersection	0
Schools within 300 m (1,000 ft) of the intersection (present/not present)	Not Present
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection	0

CMF for Bus Stops

# of bus stops within 1,000 ft. of the intersection	CMF
0	1.00
1 or 2	2.78
3 or more	4.15

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Chapter 12 SPFs for Urban and Suburban Arterials	SPF Components by Collision type	SPF Equations and Exhibits
Roadway segments	multiple-vehicle nondriveway collisions	Equation 12-10, 12-11, 12-12, Exhibits 12-5, 12-6, 12-7
	single-vehicle crashes	Equations 12-13, 12-14, 12-15, Exhibits 12-8, 12-9, 12-10
	multiple-vehicle driveway-related collisions	Equations 12-16, 12-17, 12-18, Exhibits 12-11, 12-12, 12-13, 12-14, 12-15, 12-16
	vehicle-pedestrian collisions	Equation 12-19 Exhibit 12-17
	vehicle-bicycle collisions	Equation 12-20, Exhibit 12-18
Intersections	multiple-vehicle collisions	Equations 12-21, 12-22, 12-23, Exhibit 12-19, 12-20, 12-21, 12-22, 12-23, 12-24
	single-vehicle crashes	Equations 12-24, 12-25, 12-26, 12-27, Exhibit 12-25, 12-26, 12-27, 12-28, 12-29, 12-30
	vehicle-pedestrian collisions	Equations 12-28, 12-29, 12-30, Exhibits 12-31, 12-32, 12-33
	vehicle-bicycle collisions	Equation 12-31, Exhibit 12-34

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Ref: Highway Safety Manual, 1st Edition by AASHTO

Applicable SPF	AMF	AMF Description	AMF Equations and Exhibits
Roadway Segments	AMF_{1r}	On-Street Parking	Equation 12-32 and Exhibit 12-36
	AMF_{2r}	Roadside Fixed Objects	Equation 12-33 and Exhibit 12-37 and 12-38
	AMF_{3r}	Median Width	Exhibit 12-39
	AMF_{4r}	Lighting	Equation 12-34 and Exhibit 12-40
	AMF_{5r}	Automated Speed Enforcement	See text
Multiple-vehicle collisions and single-vehicle crashes at intersections	AMF_{1i}	Intersection Left-Turn Lanes	Exhibit 12-41
	AMF_{2i}	Intersection Left-Turn Signal Phasing	Exhibit 12-42
	AMF_{3i}	Intersection Right-Turn Lanes	Exhibit 12-43
	AMF_{4i}	Right Turn on Red	Equation 12-35
	AMF_{5i}	Lighting	Equation 12-36 and Exhibit 12-44
	AMF_{6i}	Red Light Cameras	Equation 12-37, 12-38, 12-39
Vehicle-Pedestrian Collisions at Signalized Intersections	AMF_{1p}	Bus Stops	Exhibit 12-45
	AMF_{2p}	Schools	Exhibit 12-46
	AMF_{3p}	Alcohol Sales Establishments	Exhibit 12-47

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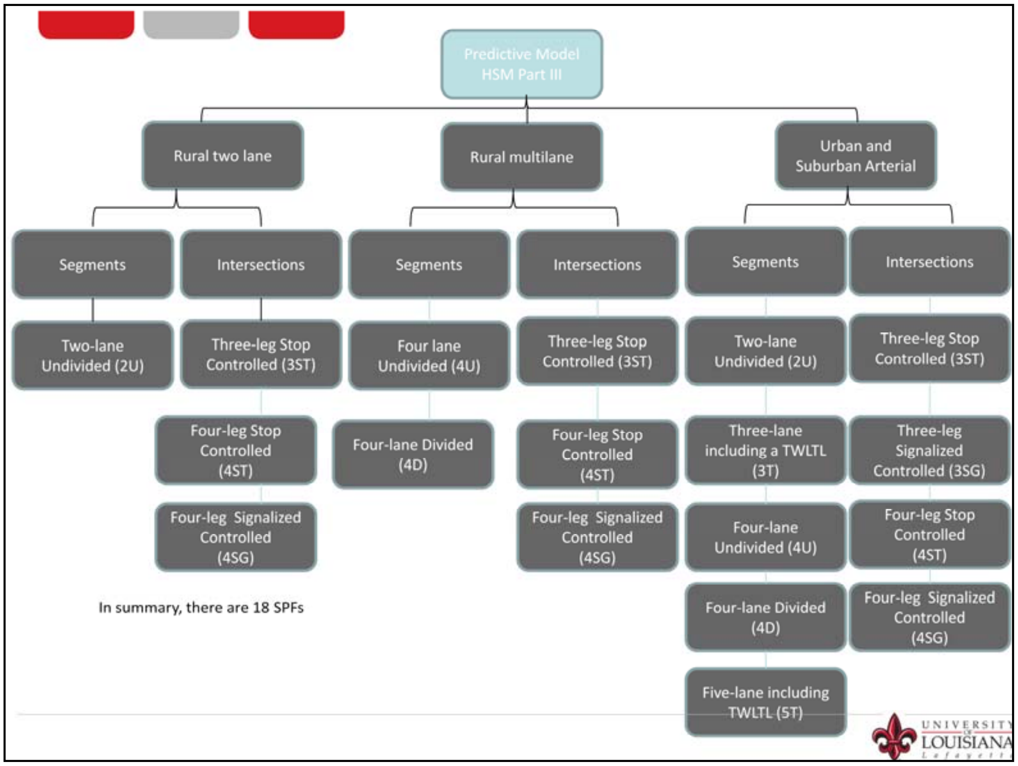

- Final summary for all models introduced in the first edition of HSM

For questions contact

xsun@louisiana.edu

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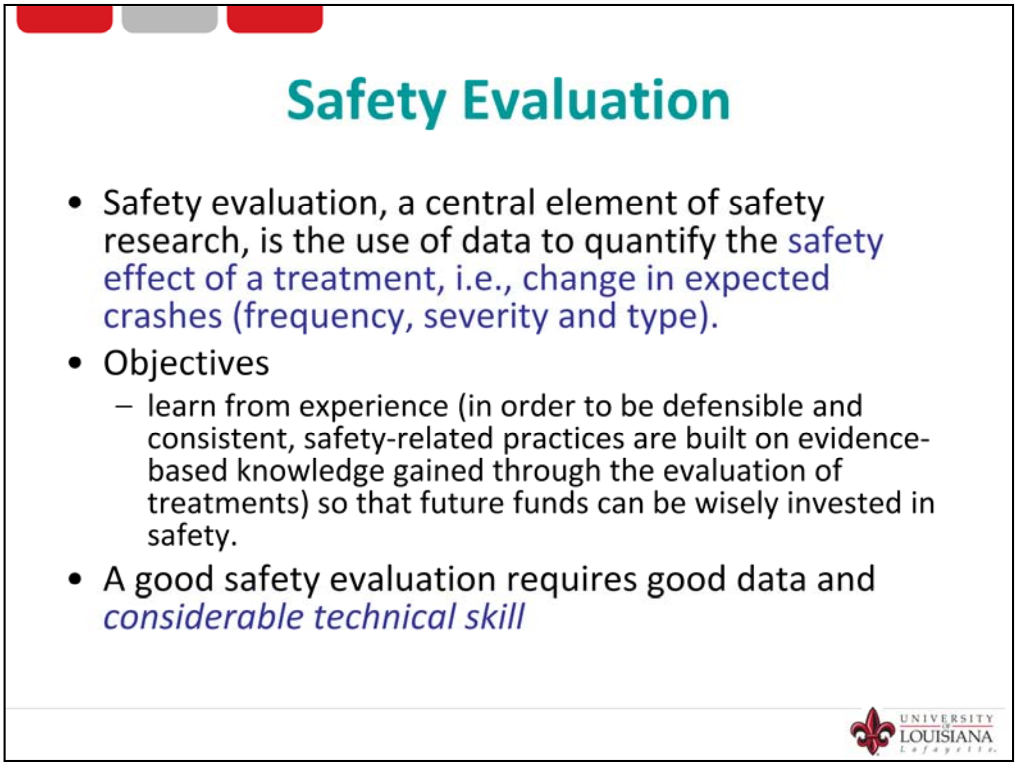
The objective of this lecture is to let students understand the purpose and requirements for safety evaluation.

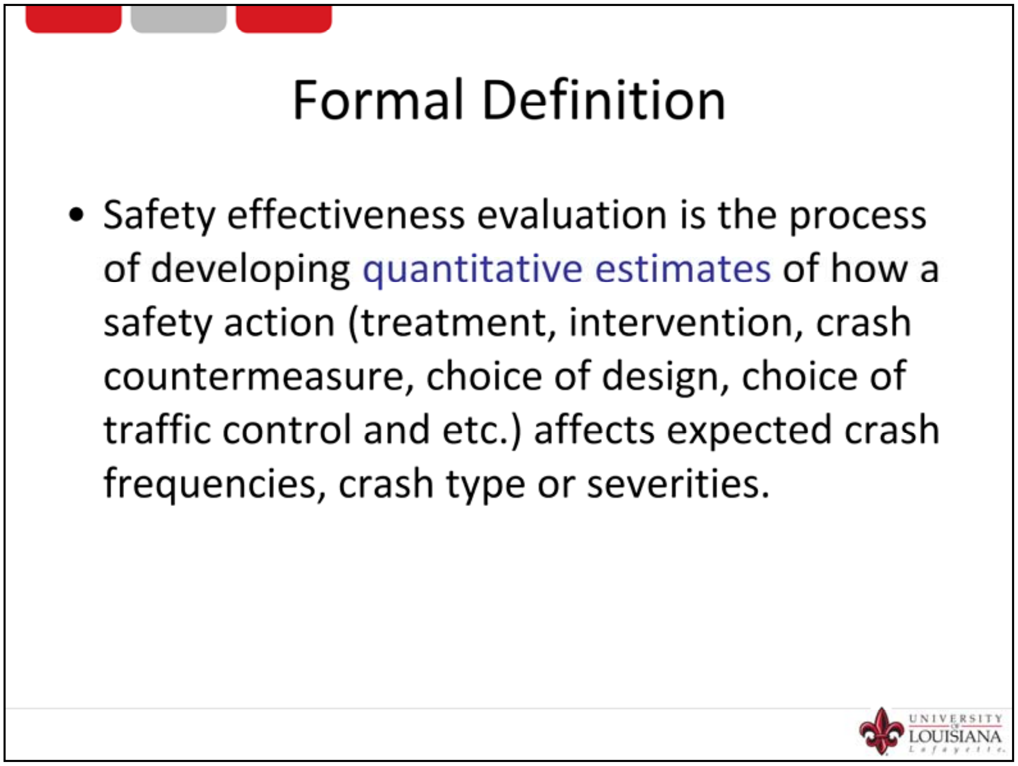
Outline

- **Introduction**
- Methods
- Case Studies

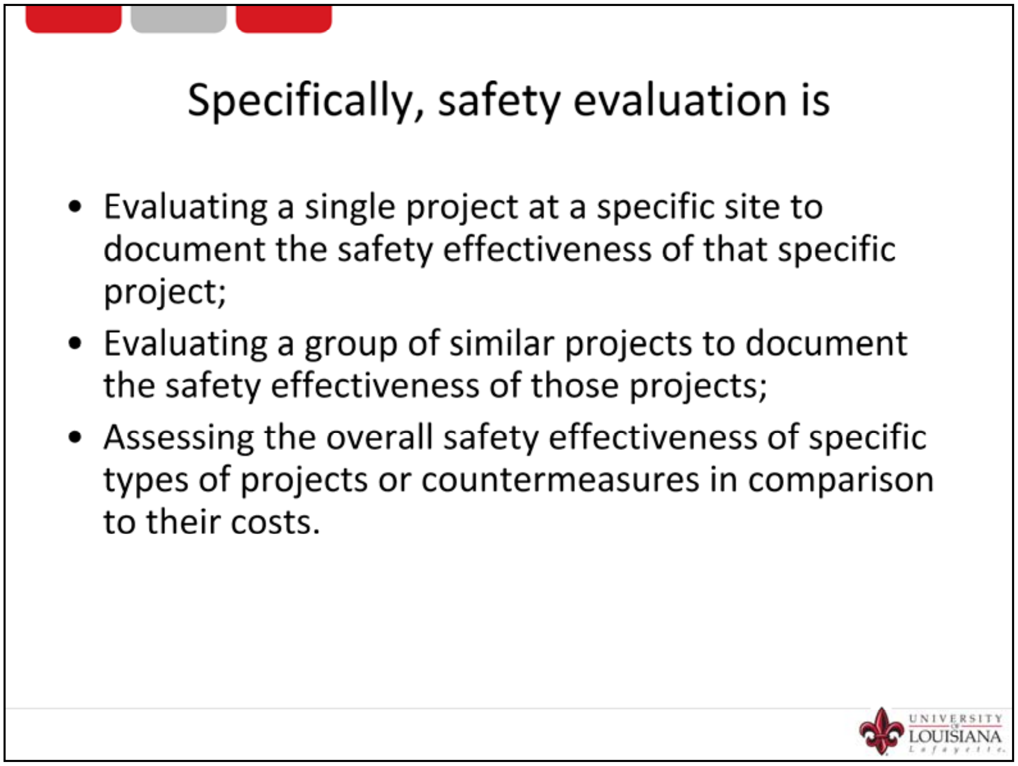


The purpose of this section is to explain the fundamentals of safety evaluation and to create an awareness of the challenges facing safety evaluation studies. The intent is also to enable student to form an opinion about the reliability and validity of the results of safety evaluations.

Emphasizing good technical skills in safety evaluation.



The effectiveness estimate for a project or treatment is a valuable piece of information for future safety decision-making and policy development.



Discuss the application of safety evaluation in the real world.

First, a question to you (students)

- What would you propose to do if you were asked to evaluate the effectiveness of a project (for instance a roundabout installed three years ago)?

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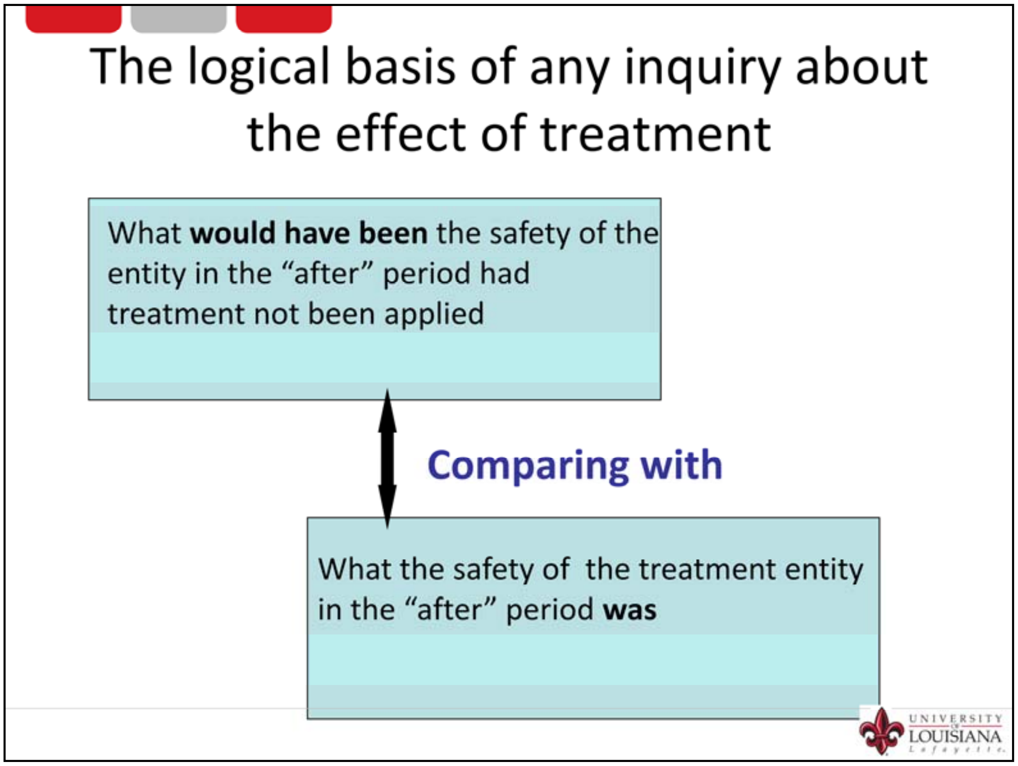
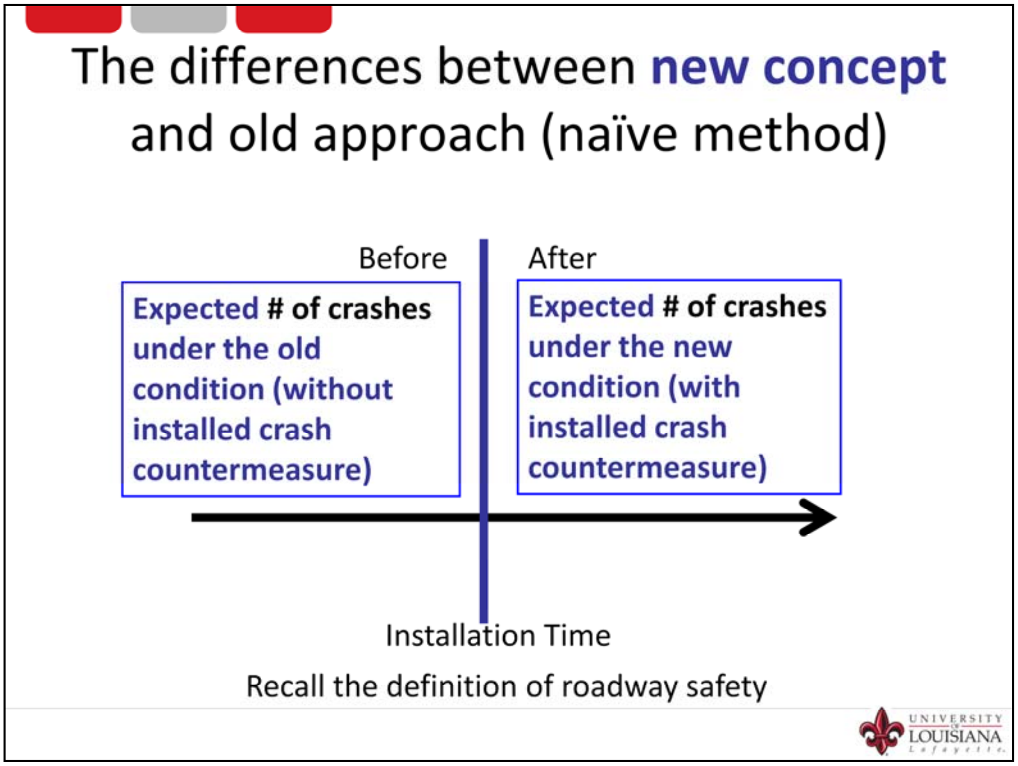
Let students participate in the discussion.

Outline

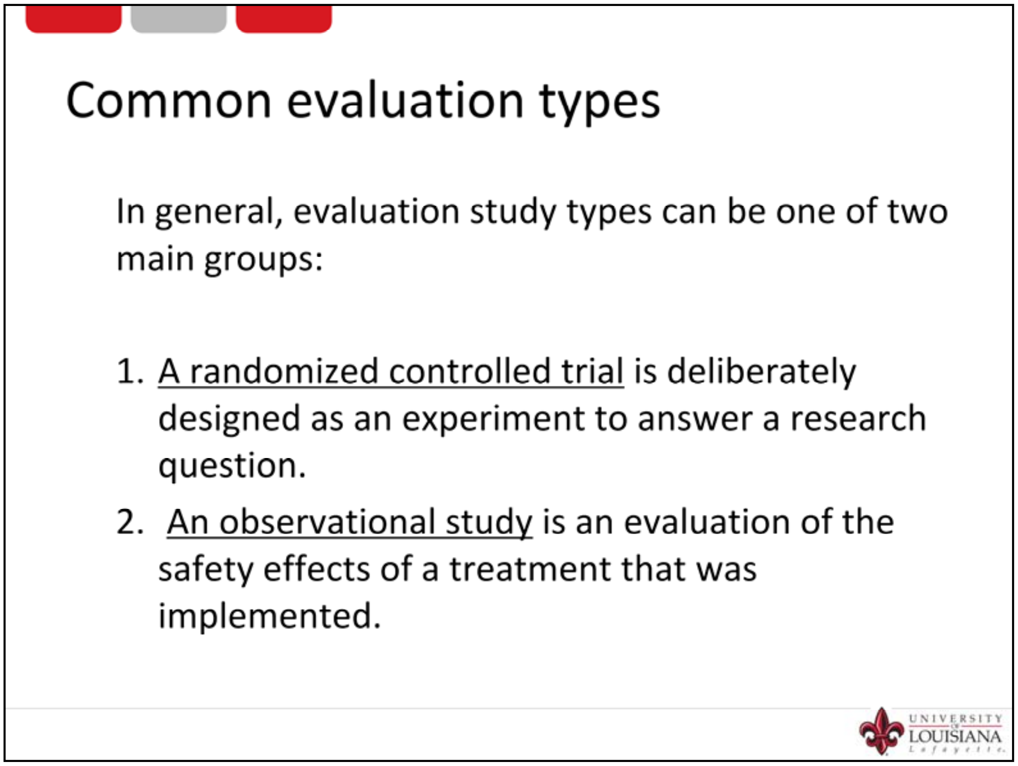
- Definition
- **Methodologies**
- Real World Evaluation Cases



Remind students of the definition of safety.



Naïve methods were widely used 15 years ago even in some transportation textbooks.

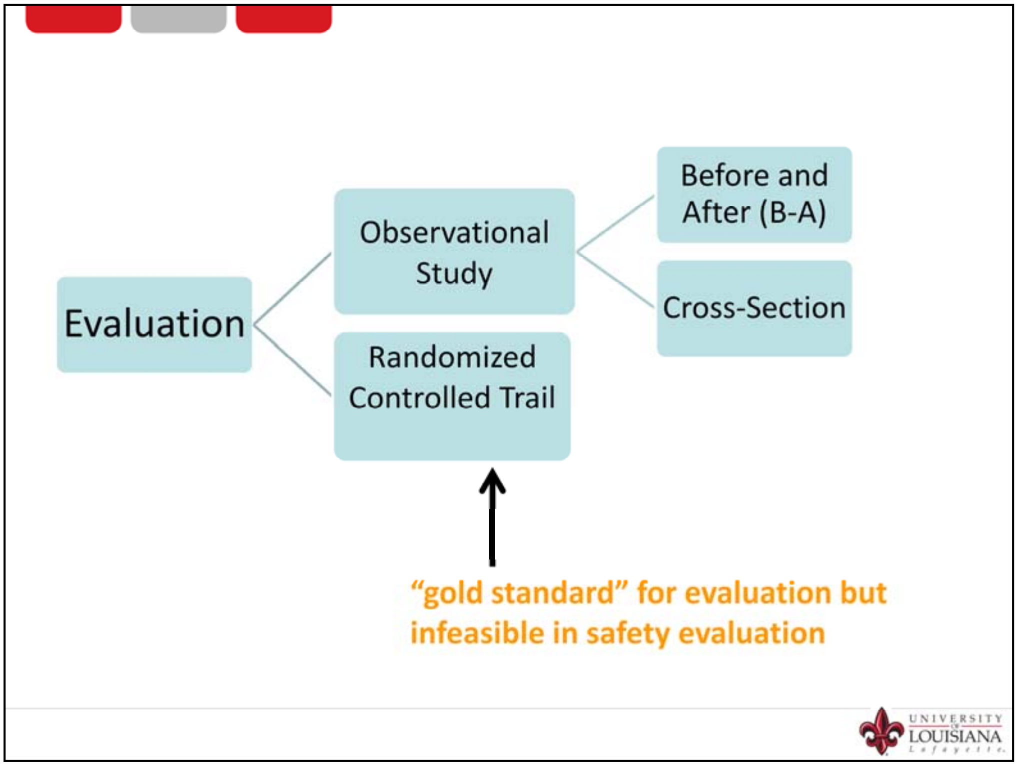


There are many ways to predict the safety of, for example, an intersection or a road section.

Some approaches are better than others. The strengths and weaknesses of the main evaluation study types are described in this lecture.

In randomized controlled trials, roadways or facilities are randomly assigned to a treatment or control group.

The key characteristic of an observational study is that the selection of roadways or facilities which receive certain treatments is not random.



Randomized controlled trials are the “gold standard” for evaluation studies that can be conducted in controlled conditions such as a laboratory. The purpose of randomization is to ensure that the prediction accounts for all changes in safety-relevant conditions, that the prediction is free of bias, and that the accuracy of results can be clearly stated. Although randomized controlled trials lead to the most defensible evaluation of the safety effects of a treatment, the randomized controlled trial study type is not common for road safety evaluations. Ask students why.

In Physics laboratory or a complete controlled study

- All other experiment conditions are controlled to remain the same; it is ok to take the shortcut of assuming that “after” measurement would have been the same as “before” measurement

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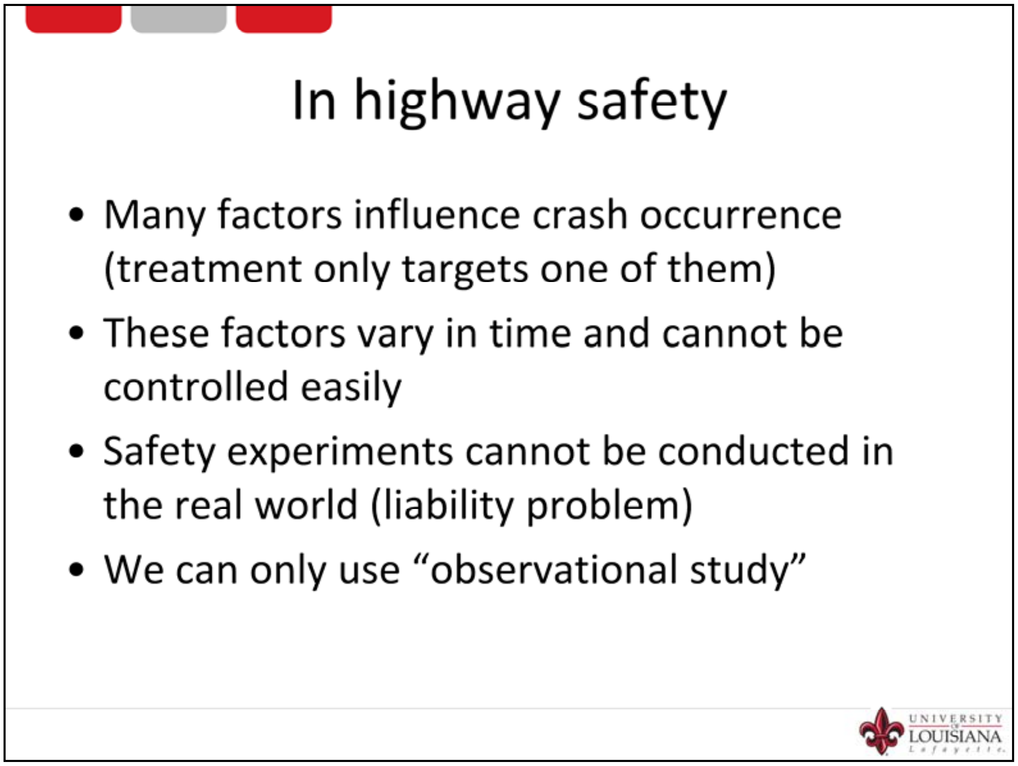
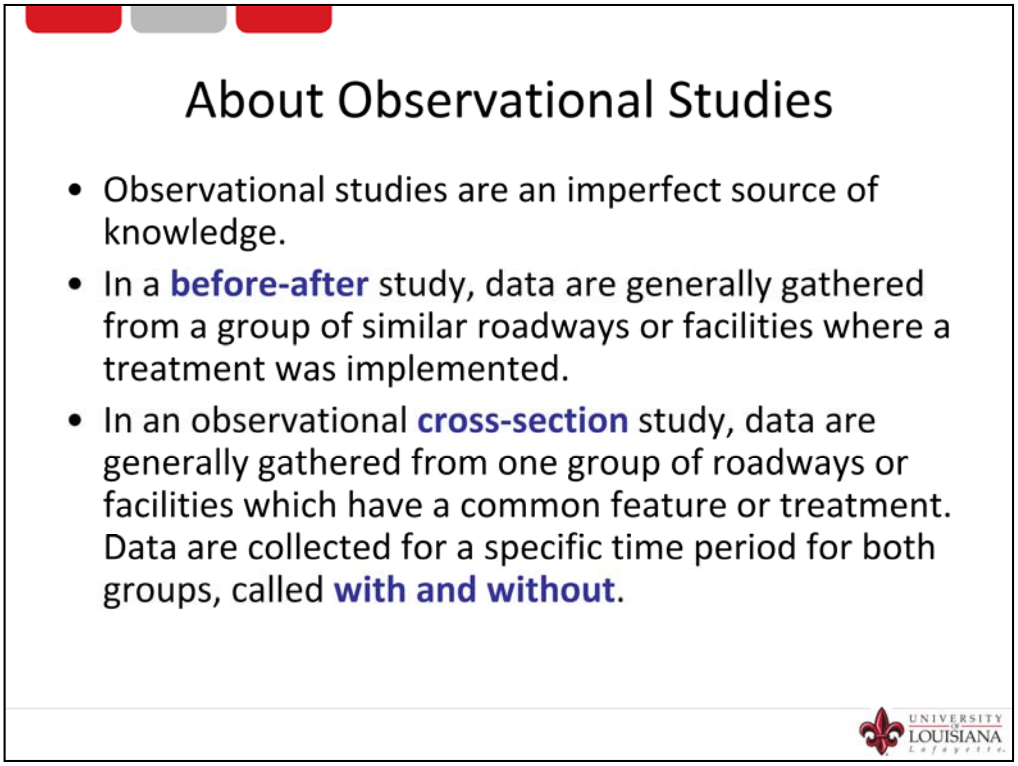
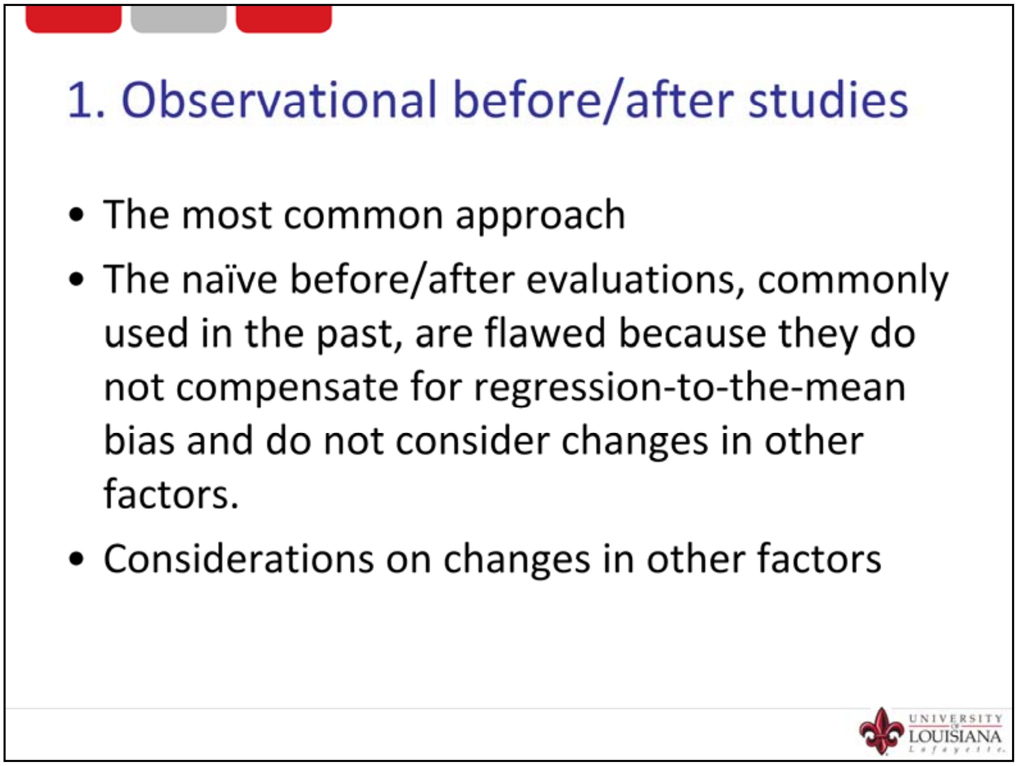
Ask students give examples on complete controlled studies they had in the past.



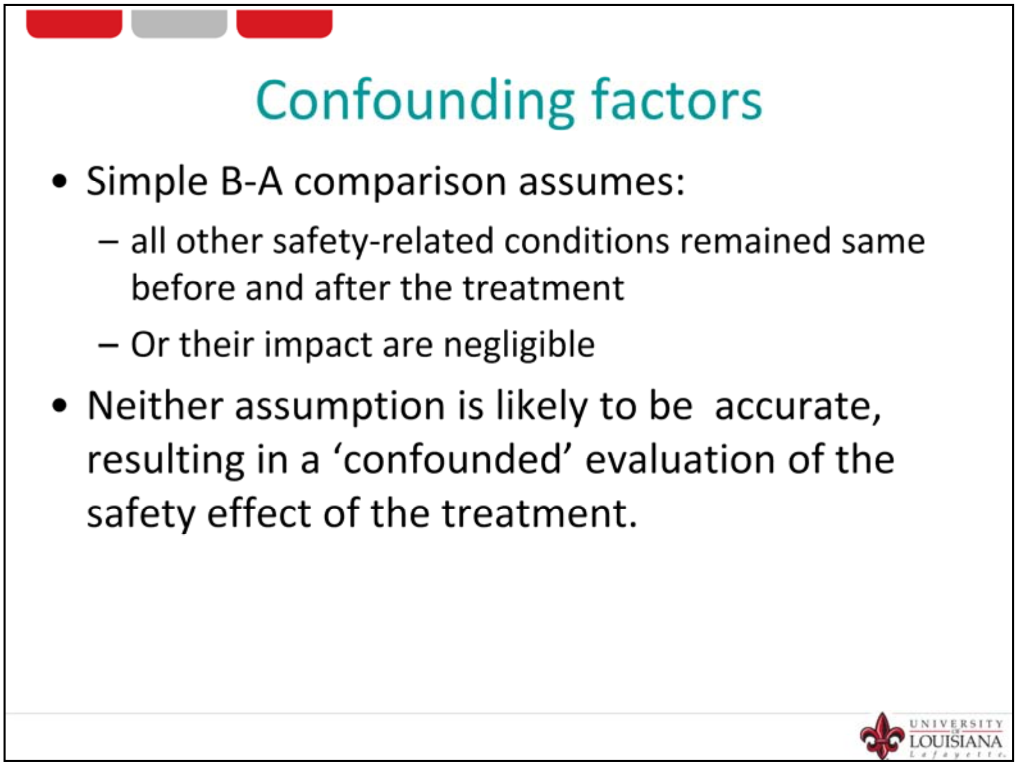
For these reasons, researchers can not design experiments, for example, roadway lane width or shoulder width, to evaluate the safety of roadway design element.



Thus, a big challenge for researchers in highway safety is to work with imperfect information.



Looking the research published 30 years ago and seeing the popularity of naïve methods in roadway safety evaluation. Safety evaluation is truly an evolved process.



The potential for confounding exists in observational before-after studies when changes in safety-relevant conditions from the "before" to the "after" period, i.e., the untreated to the treated period, are not accounted for in the prediction of safety. To simply compare accident counts on the roadway from "before" and "after" the treatment assumes that either all the safety-relevant conditions remained constant or that their impact on safety is negligible.

Regression to the mean

- Regression-to-mean bias makes a treatment seem more effective than it really is.
- Regression-to-mean bias will occur when a treatment is motivated and implemented because the number of accidents recently reported was high, and the safety evaluation fails to account for the "recent random increase."

Again on RTM: It is important for students get RTM before the end of this course and forward.

B-A Method	Method	Confounding factor	Account for RTM
	Naïve B-A (no longer acceptable)	Not considered	No
a	B-A with Comparison Group	that the change in crashes of the comparison group of roadways or facilities predicts the safety of the treated roadways or facilities if they were not treated	No
b	B-A with Explicit Corrections	Accounts explicitly for known changes in traffic and possibly for other safety relevant conditions.	No, but it can be minimized by using multiple years of data
c	B-A with EB (must have carefully developed SPF)	correct for changes that occurred in both measured and unmeasured safety relevant conditions between the before and after periods	Yes

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The first and simplest type of observational before-after study has a high potential for confounding as the safety effect of the treatment cannot be separated from the safety effect of other conditions. The naïve or simple B-A study type does not account for regression-to-mean.

The second study type is the before-after with comparison group study. This study type seeks to reduce the potential for confounding by using the before and after accident counts of a comparison (untreated) group of roadways or facilities. The assumption is that the safety-relevant conditions of the treated roadways or facilities changed from before to after in the same way as the comparison group of roadways or facilities. This assumption is unlikely and generally difficult to confirm for important safety-relevant conditions. For example, it is unlikely that traffic in the treated group of roadways or facilities changed in the same way as in the untreated group of roadways or facilities. However, if it can be shown that all safety-relevant conditions changed in the treated group of roadways or facilities just as in the comparison group, then the safety prediction is the “safety of the treatment group before treatment” multiplied by the comparison ratio. The comparison ratio is defined as the “safety of the comparison group after treatment” divided by the “safety of the comparison group before treatment.” Another difficulty of this study type occurs when the number of accidents in the comparison group is small, resulting in an inaccurate comparison ratio. The B-A with comparison group study type does not account for regression-to-mean.

B-A with Comparison Group
(treatment sits with non-treatment sites)

- The comparison group allows consideration of general trends in crash frequency or severity whose causes may be unknown, but which are assumed to influence crash frequency and severity at the treatment and comparison sites equally.
- Non-treatment sites have traffic volume, geometrics, and other site characteristics similar to the treated sites

Comparison groups used in before/after evaluations have traditionally consisted of non-treated sites that are comparable in traffic volume, geometrics, and other site characteristics to the treated sites, but without the specific improvement being installed

Data Needs and Input

- At least 10 to 20 sites at which the treatment of interest has been implemented
- At least 10 to 20 comparable sites at which the treatment has not been implemented and that have not had other major changes during the evaluation study period
- A minimum of 650 aggregate crashes at the comparable sites at which the treatment has not been implemented
- 3 to 5 years of **before** crash data is recommended for both treatment and non-treatment sites
- 3 to 5 years of **after** crash data is recommended for both treatment and non-treatment sites
- SPFs for treatment and non-treatment sites

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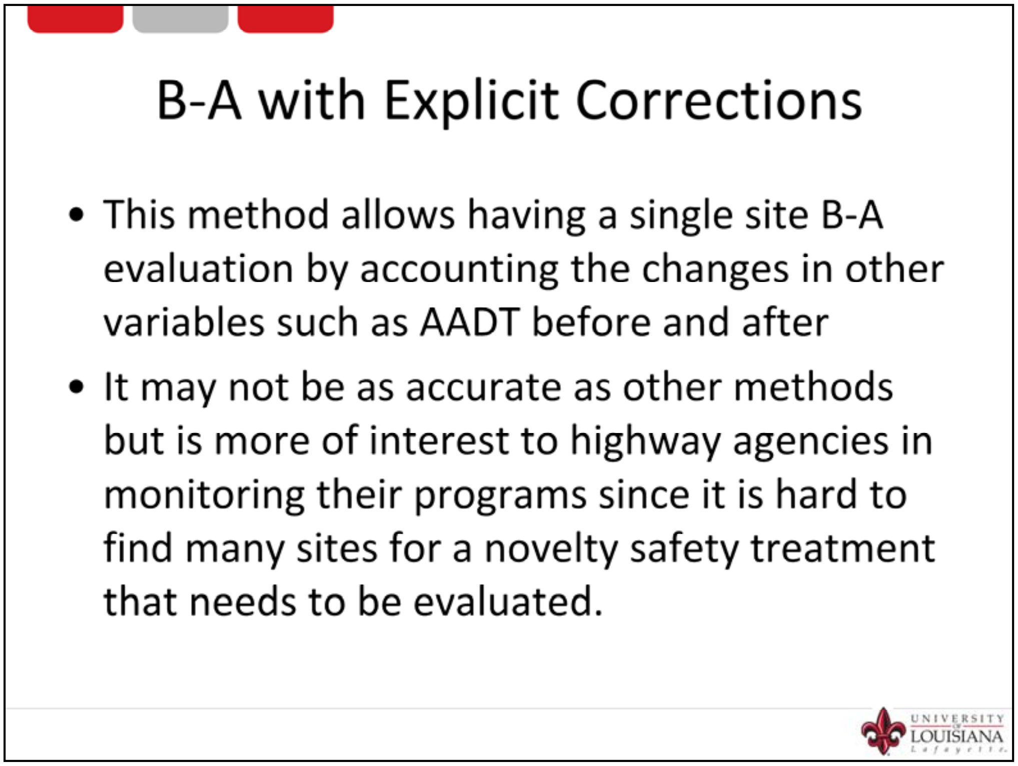
It is desired data requirements. Oftentimes, evaluation has to be done on a single site.



The results of such evaluations, even for a single site, may be of interest to highway agencies in monitoring their improvement programs. However, results from the evaluation of a single site will not be very accurate and, with only one site available, the precision and statistical significance of the evaluation results cannot be assessed.

B-A with EB

- Using SPF to estimate what the average crash frequency at the treated sites would have been during the time period after implementation of the treatment, had the treatment not been implemented.

Date Needs and Input

- At least **10 to 20** sites at which the treatment of interest has been implemented
- 3 to 5 years of crash and traffic volume data for the period **before** treatment implementation
- 3 to 5 years of crash and traffic volume for the period **after** treatment implementation
- **SPF for treatment site types**

An evaluation study can be performed with fewer sites and/or shorter time periods, but statistically significant results are less likely.

Basic Calculation Steps

$$N_{before} = N_{predicted}\omega + N_{observed}(1-\omega)$$

Must have

$$N_{after} = N_{predicted}\omega + N_{observed}(1-\omega)$$

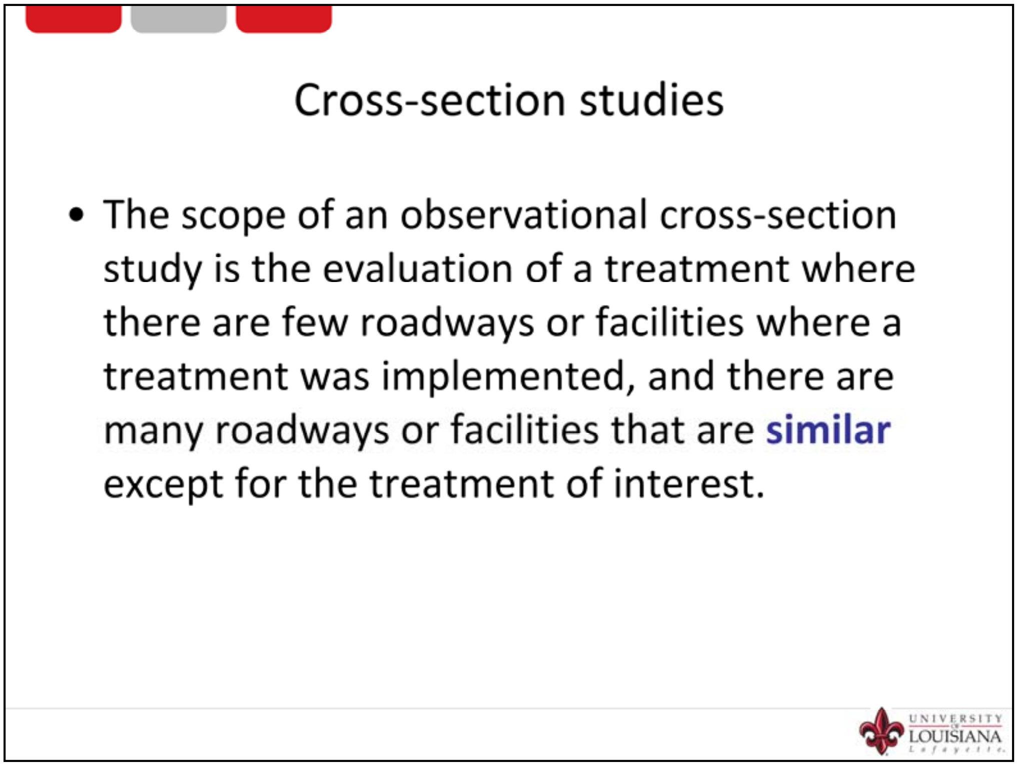
$$\Delta N = N_{before} - N_{after}$$

$$VAR(\Delta N)$$

- Estimating the expected crashes in the before period for each site with EB method
- Estimating the expected crashes in the after period for each site with EB method
- Calculating the differences (effectiveness) between before and after periods
- Estimating precision of the effectiveness

2. Observational Cross-Sectional Studies

- When treatment installation dates are not available;
- When crash and traffic volume data for the period prior to treatment implementation are not available;
- When the evaluation needs to explicitly account for effects of roadway geometrics or other related features by creating a CMF function, rather than a single value for a CMF.



For example, it is unlikely that an agency has many rural two-lane road segments where horizontal curvature was rebuilt to increase the horizontal curve radius. However, it is likely that an agency has many rural two-lane road segments with horizontal curvature in a certain range, such as 1500 to 2000 ft. (450 to 600 m) range, and another group of segments with curvature in another range, such as 3000 to 5000 ft. (900 to 1500 m). These two groups of rural two-lane road segments could be used in a cross-section study.

Data needs and input

- 10 to 20 treatment sites are recommended to evaluate a safety treatment
- 10 to 20 non-treatment sites are recommended for the non-treatment group
- 3 to 5 years of crash data for both treatment and non-treatment sites is recommended

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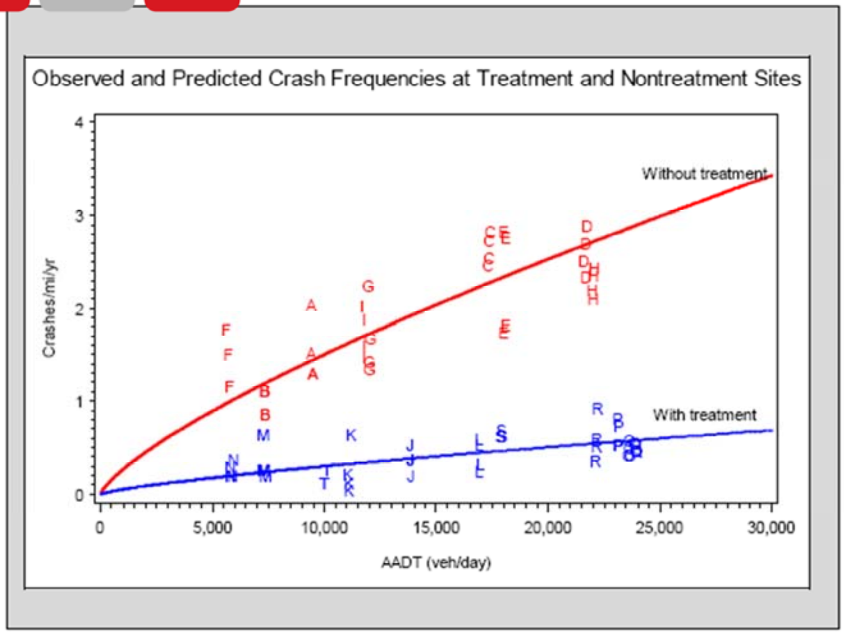

Absolute difference varies by AADT

Selection Guide for Observational Evaluation Methods

Treatment sites data		Non-treatment sites data		SPF models	Suitable Method
Before	After	Before	After		
X	X			X	B-A with EB
X	X	X	X		B-A comparison
X	X				B-A with Explicit Corrections
	X		X		Cross-sectional

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Review

- Safety evaluation is a central element of highway safety research.
- Safety research compiles lessons learned through the collective experience of highway agencies. In order to be defensible and consistent, safety-related practices are built on evidence-based knowledge gained through the evaluation of treatments.
- A good safety evaluation requires good data and considerable technical skill.

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Let’s learn the skills.

Outline

- Definition
- Methods
- **Real World Safety Evaluation Studies**
  - Atchafalaya I-10 Speed Limit Study
  - Four lane to 5 lane Conversion

Atchafalaya I-10 Speed Limit Study

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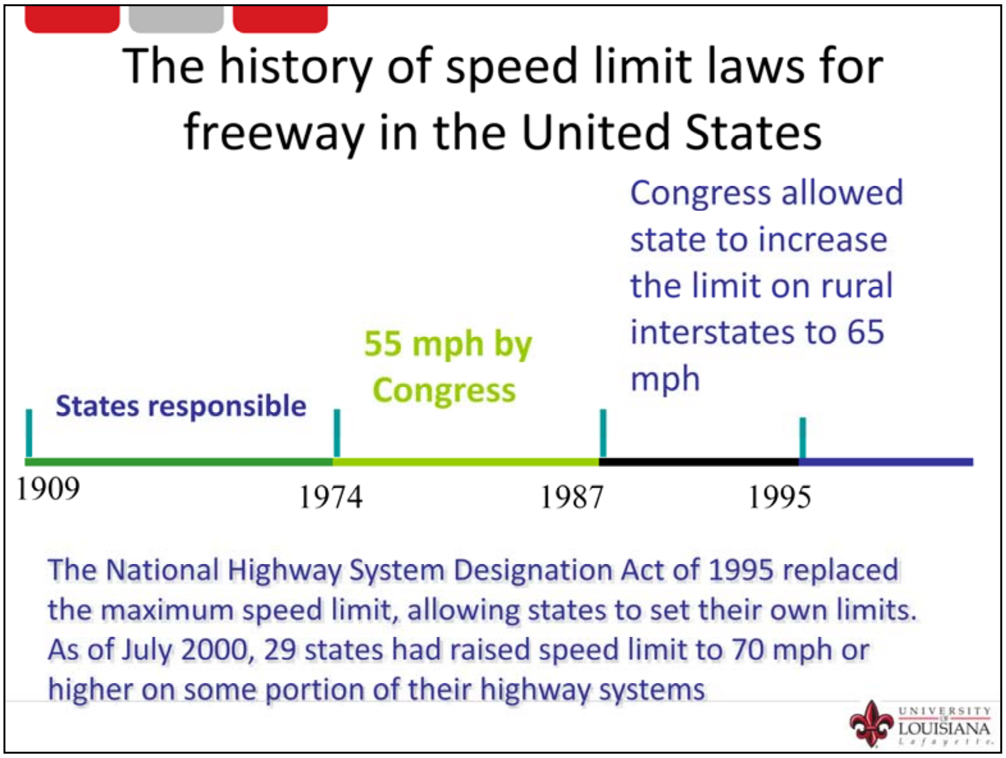


Speed limit had been traditionally the responsibility of the states since 1901.

Congress directed the USDOT to withhold highways funding from states that did not adopt a 55 mph speed limit responding to the oil shortage of 1973.

In response to claims that 55 mph limit had made the United States a nation of law breakers and assertion that accidents would not increase because people were already traveling at the speeds at which they felt comfortable, Congress allowed state to increase the limit on rural interstates to 65 mph in 1987.

The National Highway System Designation Act of 1995 replaced the maximum speed limit, allowing states to set their own limits for the first time since 1974. Many states quickly moved to raise speed limit on both rural and urban interstates and limited access roads. As of July 2000, 29 states had raised speed limit to 70 mph or higher on some portion of their highway systems.

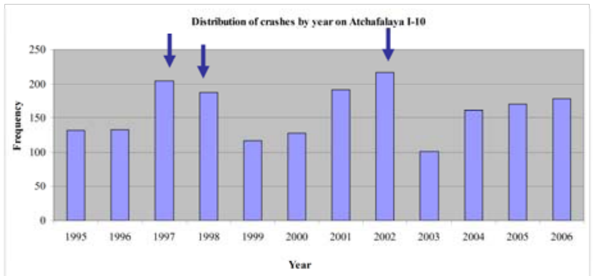
Speed Limit on I-10 at Atchafalaya Bridge

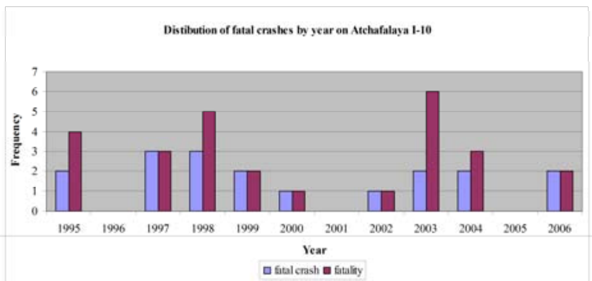
- Before 8/17/1997, the speed limit was 55 mph
- Between 8/18/97 and 8/20/98, the speed limit was 70 mph
- Since 8/21/98, the speed limit has been 60 mph
- On September 2003, the speed limit for truck (restricted on right lane) changed to 55 mph

Based 1996 and 1998 traffic crash records, Dr. Schneider's report of Analysis of the impact of increased Speed Limit on Interstate and on Highways in Louisiana" has revealed that while the # of fatal crashes increase by less than 1% in Louisiana, the fatal crash on interstate increased 37% during the same period of time.

Elevated interstates with speed limit of 70 mph had a 160% increase in fatal crashes, 134% increase in injury crashes and a 42% increase in POD crashes.

Annual Crash Statistics





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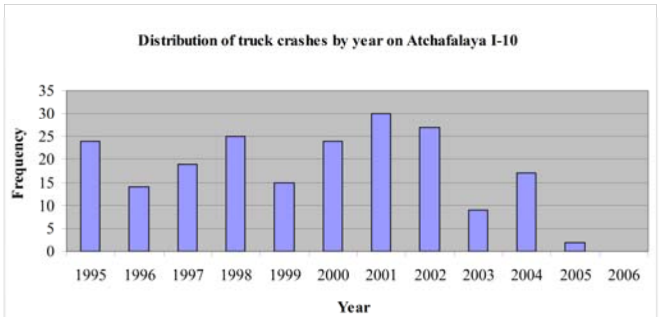
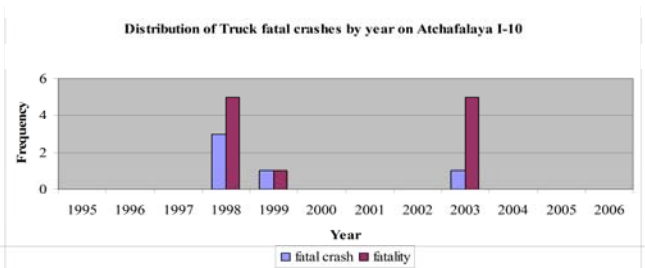
Annual Truck Crash Statistics





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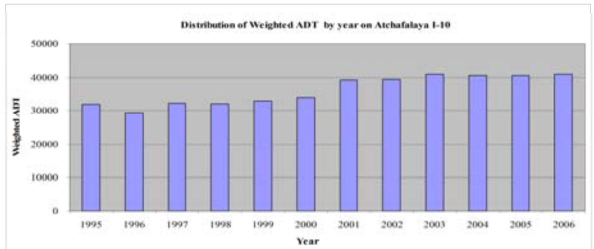
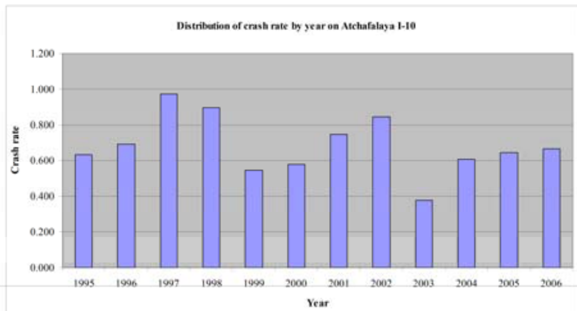
AADT and Crash Rate by Year





B-A studies

- Single site B-A study with explicit corrections
- Comparison B-A study with explicit corrections

Period	Year	Crashes	Fatal Crashes	Fatalities	AADT	Crashes	Truck Crashes	Average AADT	Fatal crashes	Fatalities
Before	2000	128	1	1	33,939	537	81	37,542	2	2
	2001	192	0	0	39,271					
	2002	217	1	1	39,415					
	2003	101	2	6	40,918	101	9	41,095	2	6
After	2004	161	2	3	40,540	509	19	40,672	4	5
	2005	170	0	0	40,540					
	2006	178	2	2	40,935					

Single site B-A study with explicit corrections

	Crashes	Average AADT
3 years before	537	37,416
3 years after	509	40,802

Step One: Estimating the safety if DSL were not installed during after period, $\hat{\lambda}$ and the safety after DSL installation $\hat{\pi}$

In this case, $\hat{\lambda} = L = 509$ $\quad$ $\hat{\pi} = \hat{r}_{tf} K = 586$

Where:

$\hat{\lambda}$ = Estimated expected number of crashes in the after period with DSL implementation

$\hat{\pi}$ = Estimated expected number of accidents in the "after" period if DSL were not used.

$\hat{r}_{tf}$ = the traffic flow correction factor $\hat{r}_{tf} = \hat{A}_{avg} / \hat{B}_{avg} = 1.09$

$\hat{A}_{avg}$ = the average traffic flow during the "after" period

$\hat{B}_{avg}$ = the average flows during the "before" period

Step Two: Estimating $\hat{VAR}\{\hat{\lambda}\}$ and $\hat{VAR}\{\hat{\pi}\}$

$$\hat{VAR}\{\hat{\lambda}\} = L$$

$$\hat{VAR}\{\hat{\pi}\} = (r_d)^2[(\hat{r}_{tf})^2 K + K^2 \hat{VAR}\{\hat{r}_{tf}\}]$$

$$\hat{VAR}\{\hat{r}_{tf}\} = r_{tf}^{\ 2}(v^2\{\hat{A}_{avg}\} + v^2\{\hat{B}_{avg}\})$$

Where:

$\hat{VAR}\{\hat{\lambda}\}$ = estimated variance of the estimated expected number of crashes in the after period,

v = the percent coefficient of variance for AADT estimates,

$$v = 1 + 7.7/\text{(number of count-days)} + 1650/\text{AADT}^{0.082}$$

$\hat{VAR}\{\hat{\pi}\}$ = estimated variance of the estimated expected number of accidents in the "after" period if DSL were not used.

$v\{\hat{A}_{avg}\} = 0.0387$

$v\{\hat{B}_{avg}\} = 0.0386$

$\hat{VAR}\{\hat{r}_{tf}\} = 0.004$

$\hat{VAR}\{\hat{\pi}\} = 1655$

$\hat{VAR}\{\hat{\lambda}\} = 509$

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Step Three: Estimating the difference $\hat{\delta}$ and the ratio $\hat{\theta}$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda}$$

$$\hat{\theta} = (\hat{\lambda} / \hat{\pi}) / [1 + V\hat{A}R\{\hat{\pi}\} / \hat{\pi}^2]$$

Where

$\hat{\delta}$ = estimated safety impact of DSL

$\hat{\theta}$ = estimated unbiased expected crash modification factor
In this application, the value of

$\hat{\delta} = 77$ $\hat{\theta} = 0.87$

Step Four: Estimating the variance of $\hat{\delta}$ and $\hat{\theta}$

$$\hat{\sigma}\{\hat{\delta}\} = \sqrt{\hat{VAR}\{\hat{\pi}\} + \hat{VAR}\{\hat{\lambda}\}}$$

$$\hat{\sigma}\{\hat{\theta}\} = \hat{\theta}\sqrt{\hat{VAR}\{\hat{\lambda}\}/\hat{\lambda}^2) + (\hat{VAR}\{\hat{\pi}\}/\hat{\pi}^2)}\,/(1 + \hat{VAR}\{\hat{\pi}\}/\hat{\pi}^2)$$

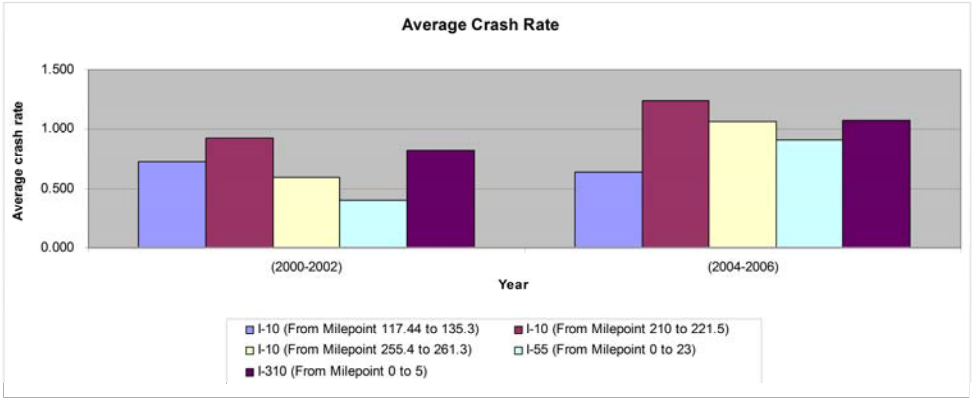
$$\hat{\sigma}\{\hat{\delta}\} = 46.52$$

$$\hat{\sigma}\{\hat{\theta}\} = 0.07$$

The interpretation is: the predicted crash reduction is 77 in three years, or 16% with DSL and truck lane restriction based on the more accurate statistical B-A analysis method. Following the same procedure, the predicted truck crash reduction is 69 in three years, or 79% with the DSL and truck lane restriction.

Comparison B-A study with explicit corrections

- Louisiana has five elevated freeways including Atchafalaya I-10. They are: I-10 over the Bonnet Carre Spillway (milepost 210 to 221.5); I-10 New Orleans East Twin Spans (milepost 255.4 to 261.3); I-55 over the Manchac Swamp (milepost 0 to 23) and I-310 over the Labranche Wetlands (milepost 0 to 5).



	Crashes Atchafalaya I-10 with DSL	Crashes Comparison Group
Before	K=537	M=1185
After	L=509	N=2002

Step One: Estimating $\hat{\lambda}$ and $\hat{\pi}$

$$\hat{\pi} = \hat{r}_T K$$

$$\hat{r}_T = \hat{r}_C = (N/M)/(1+1/M) = N/M$$

Where

$\hat{\lambda}$ = estimated expected number of crashes in the after period

$\hat{\pi}$ = estimated expected number of accidents in the “after” period if DSL were not implemented

$\hat{r}_T$ = estimated ratio of the expected accident counts for the treatment group

$\hat{r}_C$ = estimated ratio of the expected accident counts for the comparison group

$$\hat{\lambda} = 509 \qquad \hat{\pi} = 906 \qquad \hat{r}_T = \hat{r}_c = 1.688$$

Step Two: Estimating $\hat{VAR}\{\hat{\lambda}\}$ and $\hat{VAR}\{\hat{\pi}\}$

With the same assumption that number total crashes follows Poisson distribution, there is:

$$\hat{VAR}\{\hat{\lambda}\} = L$$

$$\hat{VAR}\{\hat{\pi}\} = \hat{\pi}^2[1/K + \hat{VAR}\{\hat{r}_T\}/\hat{r}_T^{\,2}]$$

$$\hat{VAR}\{\hat{r}_T\}/\hat{r}_T^{\,2} = 1/M + 1/N + \hat{VAR}\{\omega\}$$

$$\hat{VAR}\{\omega\} = s^2\{o\} - (1/K + 1/L + 1/M + 1/N)$$

$$s^2(o) = (o_i - m(o))^2$$

$$o = (KN)/(LM)/(1 + 1/L + 1/M)$$

$$m(o) = \sum_{i=1}^{n} o_i / n$$

Where

$\hat{VAR}\{\omega\}$ = the variance of the odds ratios

o= sample odds ratio

m(o) = the sample mean

$s^2\{o\}$ = sample variance

Year	Atchafalaya	Other four elevated highways	O_i	m(o)	$s^2\{o\}$
2000	128	359			
2001	192	393	0.724	1.176	0.204
2002	217	433	0.968	1.176	0.043
2004	161	523	1.614	1.176	0.192
2005	170	556	0.999	1.176	0.031
2006	178	923	1.574	1.176	0.158
Average	174	531			0.126

$\hat{VAR}\{\hat{\lambda}\} = 509$ $\hat{VAR}\{\omega\} = 0.1106$ $\hat{VAR}\{\hat{\pi}\} = 95{,}311$

Step Three: Estimating the difference $\hat{\delta}$ and the ratio $\hat{\theta}$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda}$$

$$\hat{\theta} = (\hat{\lambda} / \hat{\pi}) / [1 + \hat{VAR}\{\hat{\pi}\} / \hat{\pi}^2]$$

Where

$\hat{\delta}$ = estimated safety impact of DSL

$\hat{\theta}$ = estimated unbiased expected crash modification factor

In this application, the value of

$\hat{\delta} = 397.5$ $\hat{\theta} = 0.504$

Step Four: Estimating $\hat{\sigma}\{\hat{\theta}\}$ and $\hat{\sigma}\{\hat{\delta}\}$

$$\hat{\sigma}\{\hat{\delta}\} = \sqrt{V\hat{A}R\{\hat{\pi}\} + V\hat{A}R\{\hat{\lambda}\}}$$

$$\hat{\sigma}\{\hat{\theta}\} = \hat{\theta}\sqrt{V\hat{A}R\{\hat{\lambda}\}/\hat{\lambda}^2) + (V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2)} \,/ (1 + V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2)$$

Where

$\hat{\sigma}\{\hat{\delta}\}$ = estimated standard deviation of difference between actual number of crashes and the expected number of crashes in the after period on the treatment group.

$\hat{\sigma}\{\hat{\theta}\}$ = estimated standard deviation of the ratio of actual number of crashes and the expected number of crashes in the after period on the treatment group

$$\hat{\sigma}\{\hat{\delta}\} = 306.6 \qquad \hat{\sigma}\{\hat{\theta}\} = 0.154$$

The interpretation is: the predicted crash reduction is 398 or 50% with DSL and truck lane restriction based on the B-A comparison group analysis. Following the same procedure, the predicted truck crash reduction is 30 in 3 years, or 76% due to the DSK and truck lane restriction.

Summary

Method	Reduction in Expected Number of Crashes	Reduction in % of Crashes	Reduction in Expected Truck Crashes	Reduction in % of Truck Crashes
B-A (one site)	77 (35)	13% (6%)	69 (11)	79% (5%)
B-A with comparison Group	398 (307)	50% (15.4%)	30 (38)	64% (12%)

Number in parenthesis for variance of the estimation

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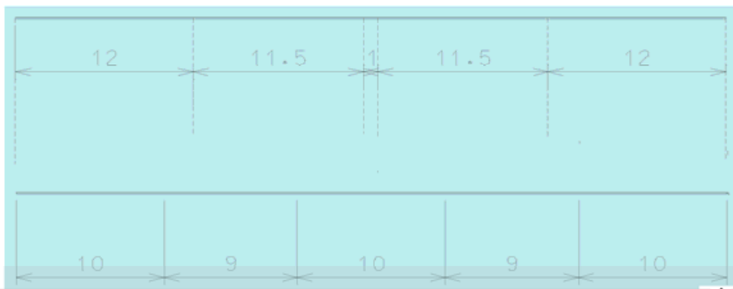
Converting a 4-lane undivided roadway segment to 5-lane roadway with middle lane for left turn



Problems with urban undivided multilane highways

- consistently exhibiting low safety performance, particularly in urban or suburban areas where driveway density is relatively high
- 1,530 miles of undivided multilane roadways under LADOTD system. 93% these roadways are in urban and suburban areas

In Louisiana, there are 1,530 miles of undivided multilane roadways and most of them are four-lane highways on the state Department of Transportation and Development System (DOTD). Ninety-three percent of these roadways are in urban and suburban areas.

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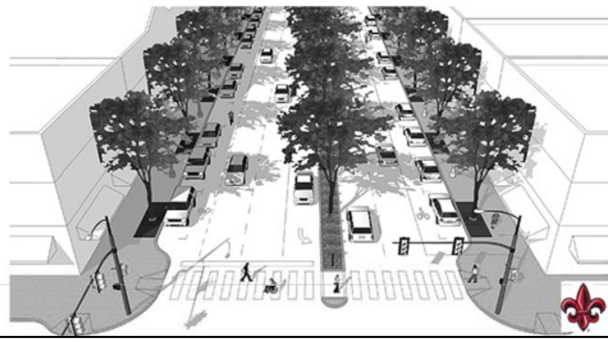
Solutions?

- Expensive solution: Installing physical separation either by barrier or by green space (boulevard) has been the most recommended crash countermeasure for the problem



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Louisiana has established policies discouraging five-lane roadway design in constructing new roads, and seldom considers it as an option in reducing crashes on undivided multilane roadways. There is no CMF listed in the first edition of the HSM for converting four-lane undivided roadway to TWLTL, and very few studies were conducted on the impact of such conversions in the past.

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Solutions?

- Inexpensive option: with sufficient pavement width, a four-lane undivided highway can also be easily changed to a five-lane roadway with the center lane for left-turns, which expectedly reduces rear-end collisions.

Pros and Cons of Two Options

- Physical barrier
  - Better traffic (motorized or non-motorized) management
  - Expensive
- Five lane
  - Inexpensive with sufficient ROW
  - Not a good layout for managing traffic
  - Not recommended for new road in Louisiana

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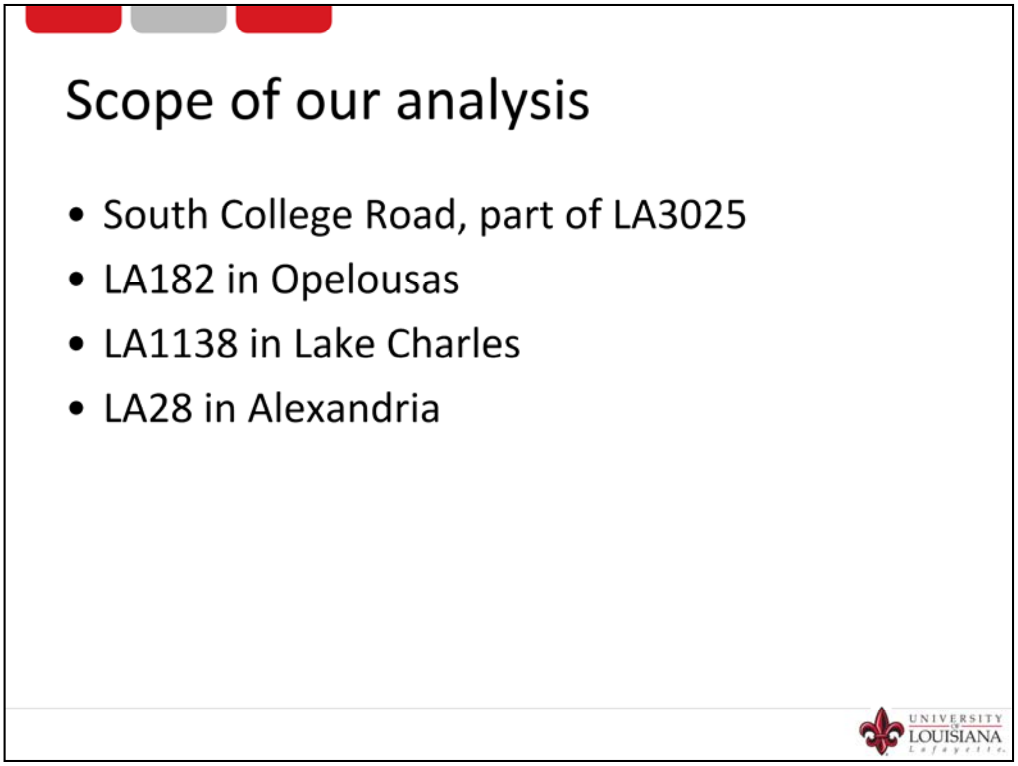
However

- Under the current budgetary situation, the expensive option is not financially feasible
- Going with the inexpensive but not perfect solution to reduce the crashes has been the only option for the situation in recent years
- Several roadway segments in various DOTD districts have implemented this inexpensive crash countermeasure in the past

CMF for the lane converting

- There is no CMF listed in the first edition of the HSM and nor is on the popular CMF clearinghouse for converting four-lane undivided roadway (4U) to TWLTL (5T)
- Only two documents list impact of such conversions based on past studies
  - Minnesota Statewide Urban Design and Specifications—crash rates 6.75 for 4U and 4.01 for 5T
  - NCHRP Report 282, National Cooperative Highway Research Program, Transportation Research Board, 1986 – reducing crashes by 45%



South College Road, part of a state route named LA3025, experienced the typical safety problems of undivided multilane roadways. It is located inside the city of Lafayette and is functioning as an arterial street. With an Annual Average Daily Traffic (AADT) around 28,000 in 2009, the majority of vehicles on the segment are through traffic.

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Summary

	District	Control Section	Length (mi)	Installation Year	No. of Driveways	Location
LA 3025	D3	828-23	1.228	2003	30	Lafayette
LA 182	D3	032-02	1	2007	50	Opelousas
LA 1138	D7	810-06	1.07	1999	50	Lake Charles
LA 28	D8	074-01	0.92	2005	20	Alexandria

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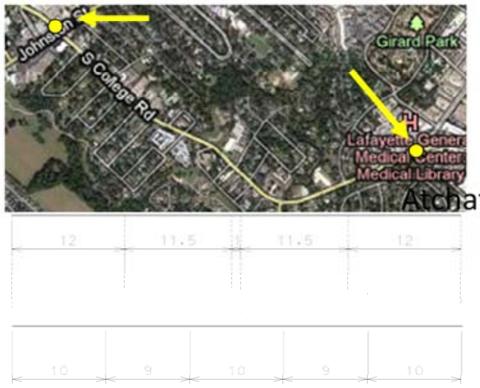
Roadway Configuration



Atchafalaya

LA3025

LA182

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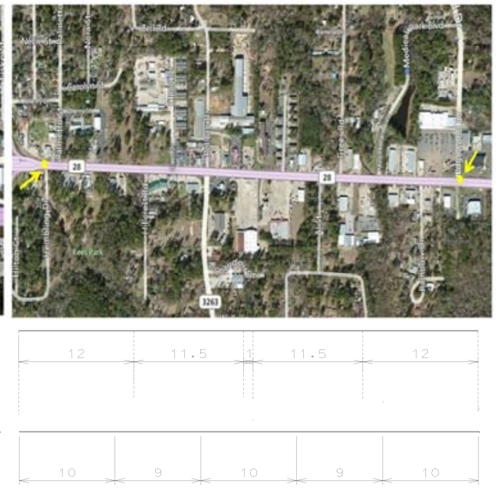
Roadway Configuration

LA1138



LA28

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Summary of Crashes

(3 years before and after)

	Before		After		Percentage Change	
	Crashes	Average Crash Rate	Crashes	Average Crash Rate	Crashes	Crash Rate
LA3025	358	10.05	147	4.59	-59%	-54.30%
LA182	178	8.12	85	3.53	-52%	-51.30%
LA28	206	7.38	99	4.09	-52%	-45%
LA1138	260	16.01	167	10.63	-36%	-34%

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Developing the CMF

- Based on the principle: the true impact of a crash countermeasure should be **the difference between the safety after the crash countermeasure implementation and the safety in the after period if the crash countermeasure were not implemented**
- Ideally, the predicted expected safety should be calculated by the Empirical Bayes (EB) method with a rigorously developed and carefully calibrated safety performance function

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Since simply comparing crash frequencies before and after a crash countermeasure implementation does not account for the changes in traffic volume and, most importantly, the stochastic nature of crashes, the analysis was conducted based on the principle that the true impact of a crash countermeasure should be the difference between the predicted safety after the crash countermeasure implementation and the predicted safety in the after period if the crash countermeasure were not implemented. Ideally, the predicted expected safety should be calculated by the Empirical Bayes (EB) method with a rigorously developed and carefully calibrated safety performance function. Since the models in Chapter 12 of the HSM for the two types of roadways are not calibrated with Louisiana data, the following “four-step” procedure introduced by Hauer (5) was used to estimate a crash modification factor for the re-striping projects assuming crashes following Poisson probability distribution. For this analysis, the actual number of crashes was used for the "predicted" crashes after the crash countermeasure implementation. The details of the safety estimation are summarized as follows…

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Developing CMF without SPF

- The "four-step" procedure introduced by Hauer in his book <u>*Observational Before –After Studies in Road Safety: Estimating the effect of Highway and Traffic Engineering measures on Road Safety,*</u>
- Used crash and AADT data three years before and three years after the project for the analysis
- Used all crashes including intersection crashes

Step 1: Estimating the safety if the re-striping were not installed during the after period, $\hat{\lambda}$ and the safety with re-striping project $\hat{\pi}$

$$\hat{\lambda} = N$$
$$\hat{\pi} = \hat{r}_{tf} K$$

	$\hat{\lambda}$	$\hat{A}_{avg}$	$\hat{B}_{avg}$	$\hat{r}_{tf}$	$\hat{\pi}$
LA 3025	147	23,888	26,580	0.90	322
LA 182	85	21,947	20,067	1.09	195
LA 28	99	26,115	25,570	1.02	210
LA 1138	167	13,540	13,870	0.98	254

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Step Two: Estimating $\hat{VAR}\{\hat{\lambda}\}$ and $\hat{VAR}\{\hat{\pi}\}$

$$\hat{VAR}\{\hat{\lambda}\} = L$$

$$\hat{VAR}\{\hat{\pi}\} = (r_d)^2[(\hat{r}_{tf})^2 K + K^2 \hat{VAR}\{\hat{r}_{tf}\}]$$

$$\hat{VAR}\{\hat{r}_{tf}\} = r_{tf}{}^2(v^2\{\hat{A}_{avg}\} + v^2\{\hat{B}_{avg}\})$$

Where:

$\hat{VAR}\{\hat{\lambda}\}$ = estimated variance of the estimated expected number of crashes in the after period,

v = the percent coefficient of variance for AADT estimates,

$v = 1 + 7.7/\text{(number of count-days)} + 1650/\text{AADT}^{0.082}$

$\hat{VAR}\{\hat{\pi}\}$ = estimated variance of the estimated expected number of accidents in the "after" period if DSL were not used.

	$\hat{VAR}\{\hat{\lambda}\}$	$\hat{VAR}\{\hat{\pi}\}$	$v\{\hat{A}_{avg}\}$	$v\{\hat{B}_{avg}\}$	$\hat{VAR}\{\hat{r}_{tf}\}$
LA 3025	147	616	0.0398	0.0395	0.0025
LA 182	85	337	0.0430	0.0425	0.0039
LA 28	99	354	0.0396	0.0397	0.0032
LA 1138	167	479	0.0423	0.0424	0.0034

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Step Three: Estimating the difference $\hat{\delta}$ and the ratio $\hat{\theta}$

$$\hat{\delta} = \hat{\pi} - \hat{\lambda}$$

$$\hat{\theta} = (\hat{\lambda} / \hat{\pi}) / [1 + \hat{VAR}\{\hat{\pi}\} / \hat{\pi}^2]$$

Where

$\hat{\delta}$ = estimated safety impact of DSL

$\hat{\theta}$ = estimated unbiased expected crash modification factor
In this application, the value of

	$\hat{\delta}$	$\hat{\theta}$
LA 3025	175	0.45
LA 182	110	0.43
LA 28	111	0.47
LA 1138	87	0.65

Step Four: Estimating the variance of $\hat{\delta}$ and $\hat{\theta}$

$$\hat{\sigma}\{\hat{\delta}\} = \sqrt{V\hat{A}R\{\hat{\pi}\} + V\hat{A}R\{\hat{\lambda}\}}$$

$$\hat{\sigma}\{\hat{\theta}\} = \frac{\hat{\theta}\sqrt{V\hat{A}R\{\hat{\lambda}\}/\hat{\lambda}^2) + (V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2)}}{(1 + V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2)}$$

	$\hat{\sigma}\{\hat{\delta}\} = \sqrt{variance}$	$\hat{\sigma}\{\hat{\theta}\} = \sqrt{variance}$
LA 3025	27.62	0.051
LA 182	20.53	0.062
LA 28	21.28	0.062
LA 1138	25.42	0.075

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Results of the Analysis

	Expected Crash Reduction	Standard Deviation	Estimated CMF or (CRF)	Standard Deviation
LA3025	175	27.62	0.45 (0.55)	0.051
LA182	110	20.53	0.43 (0.57)	0.062
LA28	111	21.28	0.47 (0.53)	0.062
LA1138	87	25.42	0.65 (0.35)	0.075

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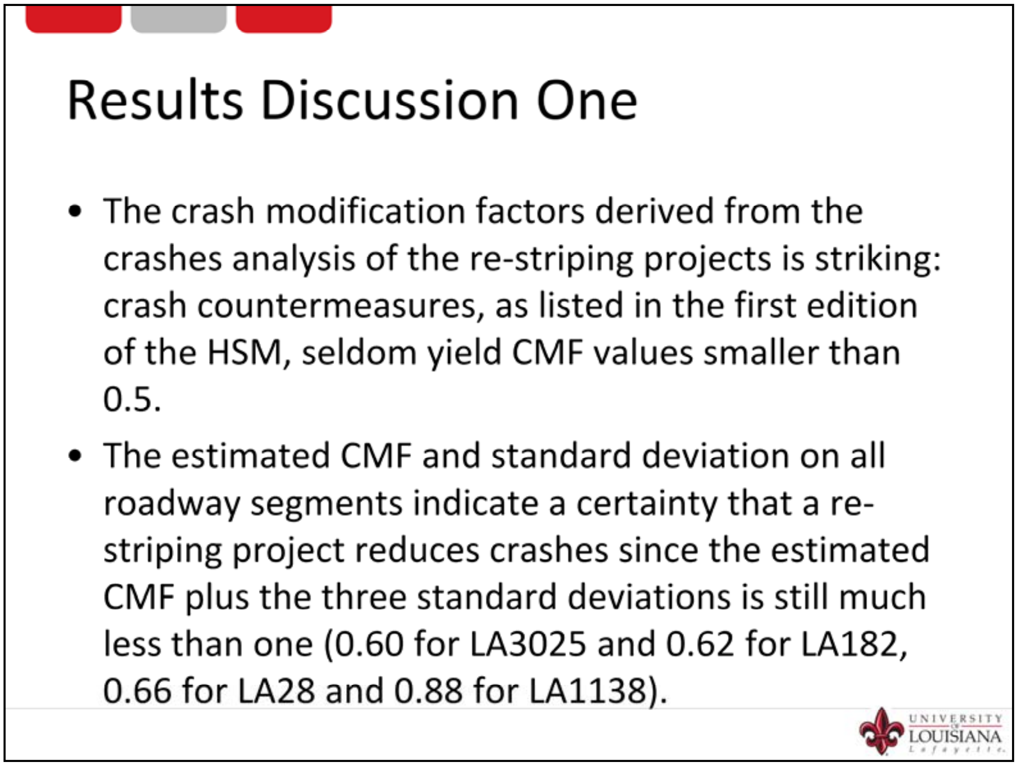

The crash modification factors derived from the before-and-after crashes analysis of the re-striping projects is striking: Crash countermeasures, as listed in the first edition of the HSM, seldom yield CMF values smaller than 0.5. The estimated CMF and standard deviation on both roadway segments indicate a certainty that a re-striping project reduces crashes since the estimated CMF plus the three standard deviations is still much less than one (0.60 for LA3025 and 0.62 for LA182). The annual crashes on LA3025 in 2008, 2009 and 2010 further confirm the sustainable effectiveness of the crash countermeasure even though the segment experienced a 10 percent increase in the average AADT from the 2004-2006 period to 2008-2010.

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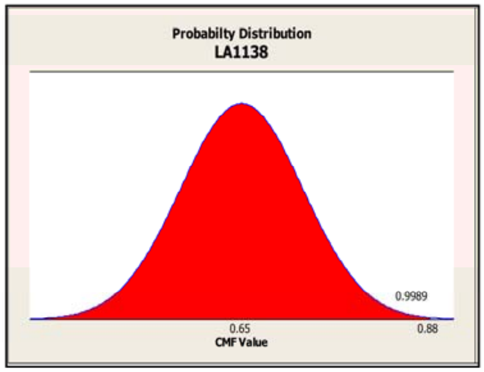
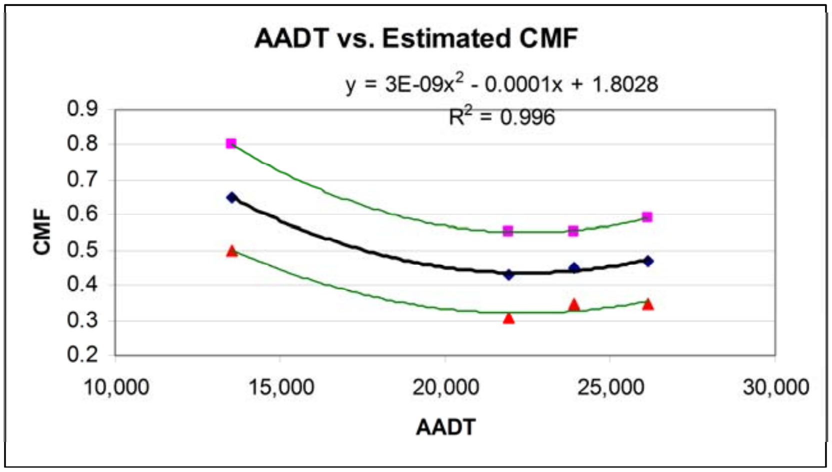
Roadway	Estimated CMF	Standard Deviation	CMF+ 3*Standard Deviation
LA3025	0.45	0.051	0.60
LA182	0.43	0.062	0.62
LA28	0.47	0.062	0.66
LA1138	0.65	0.075	0.88





AADT vs. Estimated CMF
y = 3E-09x2 - 0.0001x + 1.8028
R2 = 0.996
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
CMF
10,000
15,000
20,000
25,000
30,000
AADT

Results Discussion One (continuing)

- Although all the intersection crashes are not excluded from the analysis, the impact of the re-striping project should not be overestimated since the configurations of all intersections remain the same before and after the re-striping projects.

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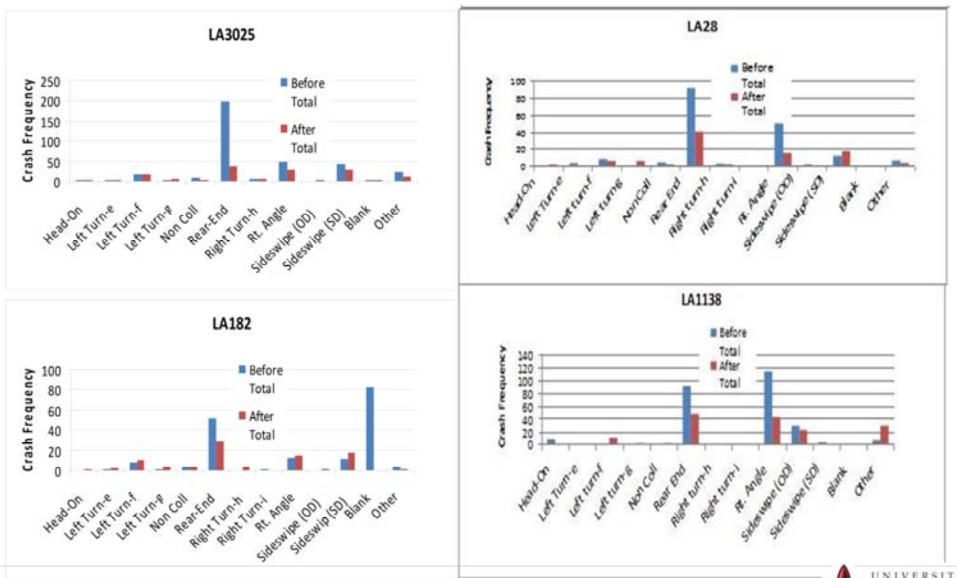
Changes in Crash Type



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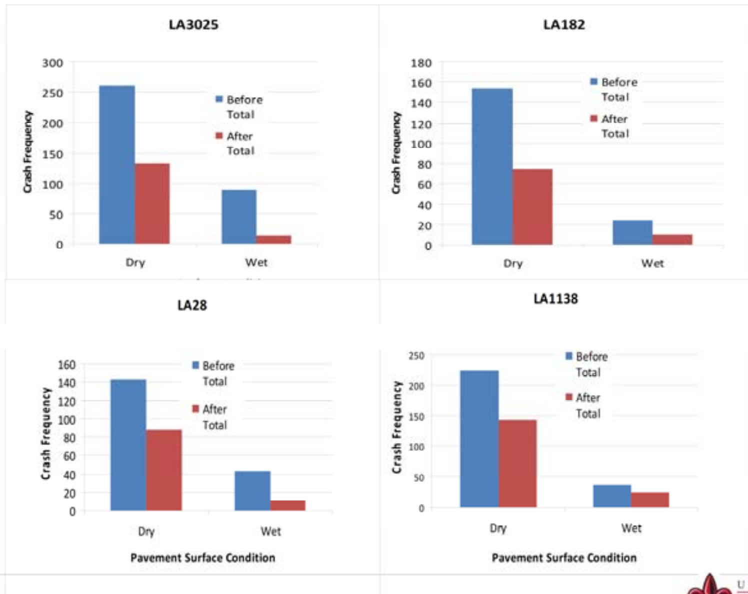
Changes by Pavement Surface Condition



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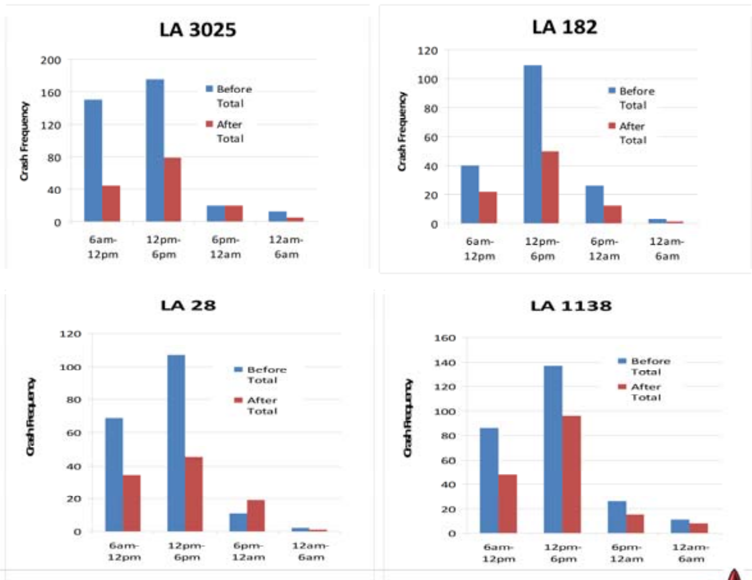
Changes by Time of Day



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Crash Severities Before and After the Re-striping Project

Crashes by Severity	LA3025			LA182			LA28			LA1138		
	Before	After	% Change	Before	After	% Change	Before	After	% Change	Befo re	After	% Change
Total	358	147	-58.90%	178	85	-52.30%	206	99	-51.94%	260	167	-35.77%
PDO	277	105	-62.10%	124	63	-49.20%	148	76	-48.68%	172	119	-30.81%
Injury Crashes	81	40	-50.60%	54	22	-59.30%	58	23	-60.34%	88	48	-45.45%
Fatal	0	2	increase	0	0	0%	0	0	0%	0	0	0%

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Results Discussion Two

- Reductions are consistent across crash category
- Two fatal crashes had nothing to do with the re-striping project on LA3025
- Speed limit reduction (from 50 mph to 45 mph) on 44% of LA182 segment after the re-striping project may not have impact on crashes frequency but may have on crash severity based on our knowledge on operating speed

While nothing was changed except the lane configuration on LA3025, there was a speed limit reduction (from 50 mph to 45 mph) on 44% of LA182 segment after the re-striping project. Without collecting speed data before and after the re-striping project and not having speeding enforcement cameras on this segment, the impact of speed limit change on operating speed is not clear. However, the numerous past studies on speed have shown that operating speed is seldom controlled by speed limit unless enforcement is present; and speed change has no statistically significant effect on crash frequency but does associate with crash severity. It is possible that the higher percentage of injury reduction on LA182 (comparing to the one on LA3025) could be somewhat associated with the speed limit change.

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Benefit/Cost Ratio

- Benefit—saving from reduced crashes
- Cost – striping
- Minimum B/C=166!

Severity Level	LA 3025 Reduction	LA 182 Reduction	LA 28 Reduction	LA 1138 Reduction
PDO	172	61	72	53
Injury	41	32	35	40

Segment	Total Benefits ($)	Total Cost ($)	B/C Ratio
LA 3025	2,753,868	14,100	195
LA 182	1,913,808	11,500	166
LA 28	2,110,212	10,600	199
LA 1138	2,317,488	12,300	188

The cost of re-striping a roadway per mile covering both materials and labor is about $7,105 by the maintenance crew of the DOTD District Office or $11,450 by outside contract. Based on the Federal Highway Administration estimation the average cost for an injury crash is $24,390, and for a PDO is $3,730; this yields a benefit to cost (B/C) ratio of **88** for the LA182 segment if using an outside contract (assuming the paint lasts about three years). This is the most conservative B/C ratio: it would be larger if maintenance crew costs were used for the LA182 project and much larger if the LA3025 crash data were used.

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Sustainable crash reduction

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Discussion Three

- Demonstrating the need for flexibility in selecting the best safety improvement project under the existing constraints (financial or otherwise).
- If and when funds do become available and sufficient right-of-way (ROW) can be obtained, these two 5-lane roadway segments can be converted to a boulevard roadway type, a concept very much promoted today in urban and suburban areas in Louisiana
- Be careful about one-size-fits-all solutions
- The HSM predictive models? (this project makes a potential contribution)

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Case Study Summary

- Without SPFs, the case studies used the best methodology with the available data
  - Three years before and after for each site
- The key is to account for AADT-- the crash influential variable
- Both studies used small sample size because of availability of data. In real world, it is infeasible to do such analysis with large sample.

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APPENDIX B: EVALUATION PACKAGE

Evaluation Package

- Homework
- Quiz
- Exam

A project Sponsored by National Center for Intermodal Transportation for Economic Competitiveness and conducted by University of Louisiana at Lafayette

November 2013

Homework One

1. Write a one-page brief (single-space) on what **you think** about highway safety in general before taking this class and what should be done to reduce number of crashes.

2. Search information online about annual traffic crashes (by type and severity) in your state and develop charts in Excel to show the trends.

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Homework Two

1. Conduct the following crash data analysis with the given data on five segments of freeway and four segments of rural and urban street:
   - Developing chart to show annual crashes by year
   - Plotting the relationship between AADT and crashes for each type of highway
   - Discussing observed RTM

2. Using the average crash calculated from the first freeway segment as mean to plot Poisson distribution curve and answer the following questions:
   - Probability of having 5, 10, 50 and 100 crashes in the coming year .
   - Probability of having less than 130 and more than 20 crashes in the coming year

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See the solution file.

Homework Three

1. Perform Exploratory Data Analysis (with Excel Pivot Table)
   step one: Open file “ HW3 Pivot.xlsx”
   Step two: Conduct an Initial EDA.
   - How many segments have 5000<ADT<5999 and 1<Length<1.5 miles? How many crashes in this group? How many crashes/segment in this bin?
   - Plot crashes/segment as a function of segment Length when 1000<AADT<2000 and 2000<AADT<3000.
   - Plot crashes/segment as a function of AADT for segment length 0.5-1 and 1-1.5, respectively.
   - Plot variance as a function of segment length for AADT (0-999) and AADT (1000-1999)
   - Discuss any trend, outliers and patterns you can identify in above chart

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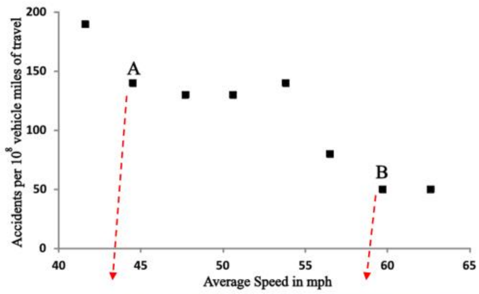
See the solution file.

2. Discuss why or why not a model can be developed based on the following data (showing increasing the average speed on a road reduces the accident rate).



Homework Four

With Louisiana rural 2-lane data (2003), you are required to estimate parameters and evaluate the following two models:

$$\hat{E}\{\mu\} = \beta_0 L^{\beta_1} AADT^{\beta_2}$$

$$\hat{E}\{\mu\} = AADT * 364 * L * e^{(-\beta)}$$

- Estimate parameters by OLS and MLE methods with solver.
- Develop CURE plot by AADT and segment length (L).
- Discuss the results.

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See the solution file.

Quiz One

Answer the following questions to the best of your knowledge

1. **The number of 2012 traffic fatalities in the U.S. is about:**
   a. 100,000
   b. 500
   c. 4,500
   d. 37,000

2. **Highway Safety is a:**
   a. Public health problem
   b. Economic problem
   c. Liability problem
   d. All of the above

3. **Over the past 50 years the traffic fatality rate in the U.S. has**
   a. Remained fairly constant..
   b. Increased slowly.
   c. Declined a little.
   d. Declined substantially.

4. **The U.S. national average fatality rate in recent years is close to:**
   a. 2.0
   b. 1.5
   c. 0.1
   d. 0.9

5. **Which of the following are included in the traditional 4Es of roadway safety?**
   a. Engineering, enforcement, education, and environment
   b. Engineering, enforcement, education, and emergency response
   c. Engineering, enforcement, education, and economic development
   d. Engineering, enforcement, emergency response and everyone else

6. **In a typical day, more people are killed in the United State by:**
   a. Traffic crashes
   b. Flood
   c. Fire
   d. Criminal actions

7. **Which of the following roadway type has the highest traffic fatality rate in the U.S.?**
   a. Freeway
   b. Multilane highway
   c. Rural 2-lane highway
   d. Urban 2-lane highway

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Answer:
1. d
2. d
3. d
4. d
5. B
6. A
7. C

Quiz Two

Answer the following questions to the best of your knowledge

1. **Which of the following safety measures is preferred from a science-based perspective?**
   a. The level of comfort you feel as a driver.
   b. The level of crash risk for all travelers.
   c. The number of fatalities occurring on the roadways.
   d. The number of crashes expected to occur on a highway facility during a specific period of time.

2. **Roadway safety should be evaluated by:**
   a. Headline stories.
   b. Personal observation.
   c. Careful statistical analysis
   d. Political expediency.

3. **Which age group has the highest traffic fatality rate?**
   a. 30 to 40
   b. 40 to 50
   c. Younger than 20
   d. Older than 70
   e. C and D
   f. A and B

4. **Objective safety is:**
   a. Quantifiable and independent of observer.
   b. Defined by design specifications.
   c. Perceptive.
   d. Personal experience oriented.

5. **What is RTM in crash analysis?**
   a. Rapid traffic management
   b. Release to manufacturing
   c. Risky transportation mode
   d. Regression to the mean

6. **Which of the following statements is not commonly used in roadway safety**
   a. Crash rate is calculated by number of crashes per one million VMT
   b. Fatality rate is calculated by fatalities per 100 million VMT
   c. Crash rate for intersection is calculated by crashes per million entering vehicles
   d. Fatality rate is the % of fatalities occurred annually

7. **Roadway safety should be evaluated by:**
   a. Headline stories.
   b. Personal observation.
   c. Careful statistical analysis
   d. Political expediency.

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Answer:

1. d
2. c
3. e
4. a
5. d
6. d
7. c

Quiz Three

Answer the following questions to the best of your knowledge

1. **Safety Predictive Models introduced by the HSM are typically used to explore the relationships between:**
   a. Aggregated crashes and roadway attributes that affect safety such as AADT and highway design features.
   b. Young drivers and inexperienced drivers.
   c. Truck crashes and bus drivers.
   d. Pedestrians and bicyclists.

2. **Safety Predictive Models introduced by the HSM are used extensively to gain insight into the safety performance of:**
   a. Roadway
   b. Driver behavior
   c. Automatic enforcement actions
   d. Environmental factors

3. **What is RTM?**
   a. Rapid traffic management
   b. Rate transportation management
   c. Risky transportation mode
   d. Regression to the mean

4. **Objective safety is:**
   a. Quantifiable and independent of observer.
   b. Defined by design specifications.
   c. Perceptive.
   d. Personal experience oriented.

5. **The first edition of Highway Safety Manual was published by:**
   a. Federal Highway Administration
   b. AASHTO
   c. ASCE
   d. ITE

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Answer:

1. a
2. a
3. d
4. a
5. b

Quiz Four

Answer the following questions to the best of your knowledge

1. **In general, the relationship between crash frequency and AADT is:**
   a. Linear, as AADT increases, crash frequency increases.
   b. Non-linear, as AADT increases, crash frequency increases.
   c. Linear, as AADT increases, crash frequency decreases.
   d. Non-Linear, as AADT increases, crash frequency decreases.
2. **What does EDA stand for in safety model development process?**
   a. Electronic Data Access
   b. Exploratory Data Analysis
   c. Electronic Design Automation
   d. Economic Development Administration
3. **The safety model parameters (coefficients) estimation depends on:**
   a. Selection of objective function.
   b. Selection of functional form.
   c. Selection of variables.
   d. All of the above
   e. None of the above
4. **Safety evaluation, a central element of safety research, is the use of data to quantify the following:**
   a. Safety effects of enforcement actions
   b. Safety effects of roadway improvements
   c. Safety effects of traffic control devices
   d. All of the above
5. **Why randomized controlled experiments (called gold standard for evaluation) cannot be used in roadway safety evaluation? Because they are:**
   a. Not scientific.
   b. Requiring too much data.
   c. Taking too much time.
   d. Not practical and inducing liability problems.
6. **Which of the following is not correct about safety modeling?**
   a. A safety model development is not a pre-defined process
   b. It is a gradual progress towards a satisfactory result consisting of steps and missteps.
   c. It does not need sufficient data as long as the right variables are selected
   d. The model parameters depend on the selection of objective functions
7. **For three types of roadways introduced in the HSM SPF chapters, the two basic safety analysis units are:**
   a. Curves and tangent
   b. Segment and intersection
   c. Segment with curve and segment without curve
   d. Stop sign controlled intersection and signalized intersection

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Answer:
1. b
2. b
3. d
4. d
5. d
6. c
7. b

Exam

1. Define the crash rate and fatality rate (in equation) for segment and intersection
2. Calculate the expected crashes for the following rural multilane roadways:

$$N_{spf} = e^{(a+b\times Ln(AADT)+Ln(L))}$$

$$N_{spf} = e^{[a+b\times \ln(AADT_{main})+c\times Ln(AADT_{min})]}$$

(a) A segment from one undivided 4-lane rural highway with length 3.8 miles, AADT 45,000, shoulder width 4-ft. Other conditions match the base conditions. Calibration factor is 2.6.

(b) A 4ST intersection with AADT on major road as 43,000, on minor road as 18,000. Due to the relatively high traffic volume on this rural intersection, lighting is present.

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See the solution file.

APPENDIX C: SYLLABUS FOR COMPREHENSIVE SAFETY COURSE

Department of Civil Engineering

Course Syllabus: Highway Safety

1. **Course Number & Name**: Highway Safety

2. **Credits & Contact Hours**: 3 credit hours, 3 lecture hours

3. **Instructor's Name:**

4. **Textbook:** No

5. **Important References:**
    - **Observational Before-After Studies in Road Safety** by E. Hauer, Emerald Group Publishing Limited (February 1, 1997).
    - ***Highway Safety Manual***, 1st Edition by AASHTO
    - ***Manual on Uniform Traffic Control Devices*** (MUTCD), 2009 Edition by FHWA
    - ***Roadside Safety Design Guide*** by AASHTO
    - ***Human Factors Guidelines*** for Road Systems by National Cooperative Highway Research Program (NCHRP)

6. **Specific Course Information**

    a. **Catalog Description**:
    Introduction to highway safety, fundamentals of safety analysis, highway safety management systems, safe highway design and operation, human factor in highway safety and highway safety modeling.

    b. **Course prerequisite**:
    Graduate student and senior status in Civil Engineering

7. **Course Specific Goals:**
    a. Mastering the fundamental knowledge of highway safety and being able to explain roadway traffic crash characteristics
    b. Understanding roadway safety design concepts (consistency and forgiving)
    c. Being able to apply predictive highway safety models to evaluate safety of a particular roadway facility (intersection, segment, interchange) safety under various design and traffic control conditions
    d. Being able to perform network screening and diagnostic analysis for highway safety management systems
    e. Understanding human factors in highways safety

8. **Brief List of Course Topics:**

    1. Introduction to highway safety

- Highway Crashes- an Underemphasized Problem
- Highway Safety – a Complex Field
- Introduction to the 4E approach

2. Highway safety fundamentals
    - Basic Safety Concepts
    - Safety Measurement
    - Safety Predictive Models
    - SPF in HSM
    - Safety Evaluation

3. Application of IHSDM program

4. Safety Management System Process
    - Network Screening
    - Diagnosis
    - Select Countermeasures
    - Economic Appraisal
    - Priorities project
    - Safety Effectiveness

5. Human Factor
    - Introduction human factors
    - Driving task model
    - Basic road users characteristics and limitation
        i. Visual
        ii. Mental
        iii. Expectancy
        iv. Speed perception and choice

    - Human factors in positive guidance and road design

6. Highway safety design
    - New safe roadway design concept
    - Forgiving roadside design
    - Geometric design
    - Intersection and interchange design
    - Access management
    - Pedestrian and bicycle safety design

9. Grading Policy*:* Homework 30%
Two Exams 40%
Projects 30%